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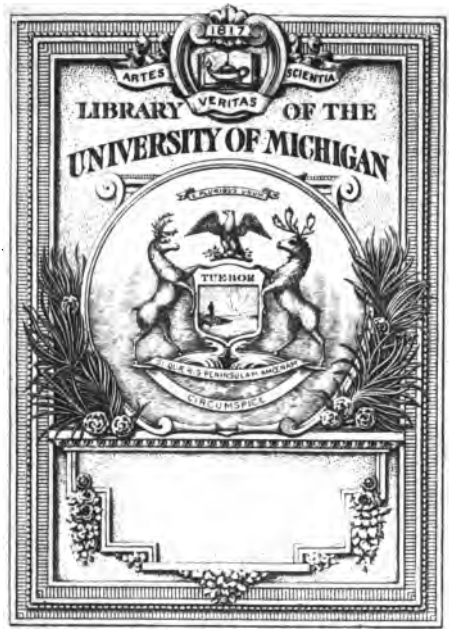
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PRACTICAL WORK

AT THE

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PRACTICAL WORK

AT THE

11383

CAVENDISH LABORATORY.

HEAT.

EDITED BY

W. N. SHAW, M.A.,

FELLOW AND LECTURER OF EMMANUEL COLLEGE.

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INTRODUCTION.

THE work of the advanced class at the Cavendish Laboratory in the department of Heat during the Michaelmas Term, 1884 consisted mainly in the repetition of some of the classical experiments in the subject, using, of course, such models of the original apparatus as the laboratory could provide. It seemed not unlikely that a somewhat detailed account of this work, although not original and therefore not suitable for presentation to a learned society, might yet furnish to students in other Laboratories information of some value respecting the practical difficulties arising, and the effect of neglecting those precautions which it was beyond the power of the Laboratory or of the observer to provide for.

In the hope that this might prove to be the case, I requested the various members of the class to make themselves responsible each for the description of one or more of the experiments comprised in the syllabus. Results had been in most cases obtained during the term by several students, working independently with the same apparatus; such results are always entered in books kept in the Laboratory for the purpose, and it was understood that they were to be incorporated in the account, the different observers being indicated by initials.

It will be seen on reference to the syllabus that the experiments are not all described. With the exception however of No. 6 their arrangement here presented no points of difference from the ordinary descriptions in the books. The apparatus for No. 6 was not completed until so late in the term that there was no time to take observations with it.

The students very kindly undertook the responsibility and wrote the descriptions which are printed below. I have done but little by way of editing; I have however added a few notes where they seemed necessary.

W. N. SHAW.

CAVENDISH LABORATORY,
January, 1885.

SYLLABUS OF ADVANCED DEMONSTRATIONS IN HEAT, 1884.

1. MANUFACTURE AND CALIBRATION OF A MERCURY THERMOMETER.
   Maxwell, Heat, Chap. ii.
   MS. Kohlrausch, Phys. Meas. p. 58.
2. COMPARISON OF MERCURY AND AIR THERMOMETERS.
   Elementary Course, No. 38.
   Balfour Stewart, Heat, Chap. iv.
   Regnault, "Sur la mesure des Températures," Mémoires de l'Académie, T. XXI.
3. THE WEIGHT THERMOMETER. DETERMINATION OF THE COEFFICIENT OF EXPANSION OF GLASS.
   MS. Regnault (l. c.).
4. COEFFICIENT OF LINEAR EXPANSION OF A ROD.
   Elementary Course[1], No. 37.
5. COEFFICIENT OF CUBICAL EXPANSION OF A METAL BY THE AREOMETRIC METHOD.
   MS. Matthiessen, Phil. Trans. 1866.
6. COEFFICIENT OF ABSOLUTE EXPANSION OF MERCURY.
   B. Stewart, § 51.
   Regnault, Mémoires de l'Académie, T. XXI.
7. DETERMINATION OF THE TEMPERATURE OF MAXIMUM DENSITY OF WATER BY JOULE'S METHOD.
   Maxwell, Chap. xvii.
8. MANUFACTURE OF AN AIR-THERMOMETER FOR USE AT COMPARATIVELY HIGH TEMPERATURES.
   MS.
9. MEASUREMENT OF HIGH TEMPERATURES BY THE RESISTANCE OF A PLATINUM WIRE.
   MS. Report of British Association, 1874, p. 242.
10. LAPLACE AND LAVOISIER'S CALORIMETER. MEASUREMENT OF THE HEAT GENERATED IN AN INCANDESCENT ELECTRIC LAMP.
    MS. Maxwell, Chap. iii.
11. BUNSEN'S ICE CALORIMETER. DETERMINATION OF THE SPECIFIC GRAVITY OF ICE.
    MS. Phil. Mag. 1871.
12. FAVRE AND SILBERMANN'S CALORIMETER.
    Deschanel, p. 442.

[1] Glazebrook and Shaw, *Practical Physics*, § 36.

13. MEASUREMENT OF HEAT BY THE METHOD OF MIXTURE. DETERMINATION OF THE LATENT HEAT OF STEAM.
    Elementary Course[1], No. 34.
    Regnault, Mémoires de l'Académie, T. XXI.

14. MEASUREMENT OF HEAT BY THE METHOD OF COOLING.
    Elementary Course[2], No. 35.
    B. Stewart, § 232.
    Regnault, Ann. de Ch. et Phys. 3 Ser. IX. p. 322.
    Dulong, Ann. de Ch. et Phys. X. p. 399.

15. CLÉMENT AND DÉSORMES' EXPERIMENT ON THE RATIO OF THE SPECIFIC HEATS OF GASES.
    Masson, Ann. de Ch. et de Phys. 3 Ser. LIII. p. 268.
    Dupré, Théor. mécan. de la Chaleur (1869), p. 87.
    Maxwell, Chap. xi.
    MS.

16. DETERMINATION OF THE SPECIFIC GRAVITY OF A VAPOUR. HOFMANN'S METHOD.
    Kohlrausch, p. 50; (edit. 1883), p. 55.

17. DETERMINATION OF THE SPECIFIC GRAVITY OF A VAPOUR. DUMAS' METHOD.
    Kohlrausch, p. 45; (edit. 1883), p. 50.

18. DETERMINATION OF THE SPECIFIC GRAVITY OF A VAPOUR. VICTOR MEYER'S METHOD.
    Kohlrausch (edit. 1883), p. 56.

19. MEASUREMENT OF THE SATURATION TENSION OF WATER-VAPOUR IN VACUO.
    Regnault, Mémoires de l'Académie, XXI. p. 481.

20. MEASUREMENT OF THE SATURATION TENSION OF WATER-VAPOUR IN AIR.
    Elementary Course[3], No. 28.
    Cam. Phil. Trans. 1883.

21. DEW-POINT MEASUREMENT. VERIFICATION OF REGNAULT'S FORMULA FOR THE WET-AND-DRY-BULB THERMOMETERS.
    Regnault, Ann. de Chimie. 3 Ser. T. XIV.
    Elementary Course[4], Nos. 29, 30.

22. COMPARISON OF THE CONDUCTIVITIES OF IRON AND COPPER.
    MS.

23. EXPERIMENTS ON RADIATION.
    B. Stewart, Book II., Chap. i.

[1] *Practical Physics*, § 39.
[2] *Ib.* § 40.
[3] *Ib.* § 42.
[4] *Ib.* §§ 43, 44.

No. 2. JOLLY'S AIR THERMOMETER[1].

In this thermometer the air is kept at a constant volume, the pressure required to keep it at that volume measuring the temperature.

The instrument consists of a glass bulb connected by means of a capillary tube with a vertical glass tube sliding up and down a fixed scale, and connected by means of india-rubber tubing with a second vertical tube sliding in front of a second scale, the divisions of which correspond with those of the first. Let us call the tube bearing the bulb the left-hand, and the other the right-hand tube. Since the india-rubber and glass-tubings are filled with mercury, we increase or decrease the pressure in the bulb, by raising or lowering the right-hand tube, and can therefore keep the air at a constant volume whatever its temperature.

The fiducial mark indicating the constant volume is the point of a small beak of dark coloured glass sealed to the interior of the tube and curving downwards.

The pressure due to the difference of level in the two tubes together with the atmospheric pressure is evidently the pressure of the gas in the bulb, and this by Charles' law is proportional to the temperature measured from -273° C.

The chief differences between Jolly's Thermometer and other instruments working on the same principle consist in increased facilities for reading. Small metal slides are placed on the tubes, which being pushed up until they exactly coincide with the top of the mercury, are more easily seen than the mercury column itself. Another improvement consists in the scales being marked on silvered glass. The reflection of the slide in the glass when exactly covered by the slide itself insures the horizontality of the line of sight and therefore the reading of the

[1] The instrument was supplied by Stollnreuther und Sohn. Munich.

correct scale division[1]. The india-rubber tubing is also an improvement; in other instruments the pressure is altered by pouring in mercury or letting it out through a tap at the bottom of the tube, or by a screw adjustment.

To work the instrument it is necessary to know the coefficient of expansion of air, this can however be experimentally obtained by means of the thermometer itself.

First, it is of the utmost importance that the air in the bulb be perfectly dry, the slightest amount of moisture will by its vapour tension vitiate the results obtained. The air is therefore pumped out and the bulb refilled by air which has been passed slowly through drying tubes containing caustic potash, calcium chloride, and phosphoric anhydride, and lastly through a cotton-wool plug to stop any dust which may be carried over; the pumping should be continued for three or four days[2].

[The bulb is cemented into an iron socket provided with a three-way tap. When dry and filled with dry air the bulb is attached by means of the socket to the manometer and all the air in the left limb of the latter driven out there by the third opening of the tap.]

The bulb is next placed in melting ice which has been previously well-washed. As the pressure of the air diminishes the mercury rises, and, if care be not taken to lower the right-hand tube, flows over into the bulb, a result to be carefully avoided as it is extremely difficult to get the last traces of mercury out. When it is thought that the air has acquired the temperature of the ice[3], the level of the right-hand tube is altered (first, by sliding the whole piece up or down, then more carefully with the micrometer screw) so as to bring the mercury up to the glass index in the bulb tube. The instrument is then left for a short time and if no change takes place in the mercury levels, readings may be taken; if a change does occur the tem-

[1] The scale must first be set vertical. This may be done by means of a plumb line.

[2] With the instrument in question a Sprengel pump was used, and before the end of the operation the mercury left the glass-tubing so highly charged with electricity as to give a spark a quarter of an inch in length.

[3] After half an hour.

perature has not yet become constant, and the operation must be repeated until it is found that no change of level occurs. The slides are then brought up to the tops of the columns and the scales read off. The operation is repeated at intervals of a few minutes and the mean of five or six such readings may be taken as the correct reading.

It is important for accurate readings that the meniscus should retain the same shape; to effect this the motion of the mercury columns immediately before each reading should be in the same direction. For example, if the mercury in the left-hand tube has been brought *up* to the index before the first reading it should not be brought *down* to it before any other reading. Should it be necessary to lower it, it must be taken lower than the index and then brought up to it.

The difference of height when in ice having been ascertained, the bulb is now placed in a hypsometer over boiling water and the same operations gone through. In this case, however, it is well to introduce a screen between the hypsometer and the manometer, as the steam blowing across the mercury columns alters their temperature and therefore their height also. The pressures at 0° and at the temperature of boiling water being now known, it is necessary to introduce corrections (1) for the expansion of glass, (2) for the volume of the capillary tube (which may be taken to be at the temperature of the room) compared to that of the bulb.

The coefficient of expansion of glass is obtained with a small weight thermometer made of the same glass as the instrument, and obtained with it (see No. 3). The ratio between the volumes of the bulb and capillary tube is ascertained by direct observation.

The coefficient of expansion of air is calculated from the following equation

$$h_0\left(V+\frac{v}{1+at}\right)=h_T\left(\frac{V(1+gT)}{1+aT}+\frac{v}{1+at}\right).$$

Where h_0 is pressure, when in ice,

h_T „ „ steam,

T the temperature of the steam,

t „ „ „ air,

$\frac{V}{v}$ the ratio of volumes of bulb and tube,

g the coefficient of expansion of glass.

After α has been obtained from this formula, the instrument can be used to determine temperatures, by taking readings in ice and then at the temperature to be determined; T can then be found by substituting in the above equation.

Examples: *To determine* α.

In Ice,	Right	Left
	229	218
	228·9	217·8
	228·9	217·8
	228·9	218
	229	217·8
	228·9	217·8
	228·95	217·86

Barometer 754·87, Temp. 15·6, Corrected pressure 752·98, Temp. of room 16·6.

Uncorrected difference 11·09. Corrected 11·057.

In Steam,	Right	Left
	551·5	274
	551·4	274
	551·5	274·1
	551·5	274·1
	551·5	274·1
	551·5	274·1
	551·48	274·07

Barometer 768·97, Temp. 14°, Corrected pressure 767·22, corresponding B. P. 100·266, Temp. of room 14·4.

Uncorrected difference 277·41. Corrected 276·687.

Therefore, $h_0 = 764{\cdot}037$, $t = 16{\cdot}6$, during 1st experiment.

$h_T = 1043{\cdot}907$, $= 14{\cdot}4$ „ 2nd „

$T = 100{\cdot}266$,

g was given by the instrument maker as ·00002749,

$\frac{v}{V}$ " " $\frac{1}{300}$,

$\therefore \alpha = ·0036764.$ (W. H.)

To compare with mercury thermometer.

Heated in bath of zinc-chloride.

	Right	Left
Mean	607·6	53·1

Barometer 757·92, Temp. 15·8, Temp. of room 16·5.

Corrected pressure 1308·53, $t = 16·6$, 1st experiment,

$= 16·5$, 2nd "

h_0 (from former experiment) 764·037,

$h_T = 1308·53$, $\therefore T = 196·74$.

Correction of mercury thermometer is therefore $-2·26$.

W. HIRD.

The observations made are included in the following Table:

Uncorrected Barometric height.	Temp. of room.	Corrected boiling point.	Mean of Observations at freezing point.		Mean of Observations at boiling point.		h_0	h_T	a	Observer.
			L. H.	R. H.	L. R.	R. H.				
30·23 in.	20°·C	100°·19	101·78	105·95	263·95	550·13	769·42	1050·42	0·003699	G. B.[1]
30·00 ,,	18°·5	100·00	264·02	274·14	264·02	555·93	769·88	1050·72	0·003701	,,
29·904 ,,	18°·0	99°·90	264·00	276·65	264·00	557·9	769·97	1050·27		,,
765·64 mm.	15°·8	100°·15	282·75	289·9	230·8	511·1	770·71	1043·10	0·00358	I. F.
761·25 ,,	17°·8	99·96	137·66	143·66	179·65	462·1	764·84	1040·42	0·003658	,,
756·6 ,,	18°·5	99·78	179·2	189·4	179·2	467·1	764·63	1041·3	0·003677	,,
758·71 ,,	17°·7		253·9	529·13			762·38			
770·91 ,,	16°·1	100·325			253·9	529·13		1044·11	0·003702	W. H.
754·87 ,,	16°·6		217·56	228·95			764·037			
768·97 ,,	14°·4	100·266			274·07	551·48		1043·907	0·003676	,,

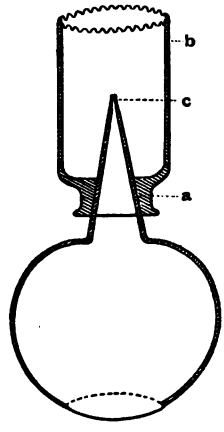
[1] A comparison of the Kew-Corrected thermometer with the air thermometer using the value of a obtained from these experiments gave:—

Mercury Thermometer.....	19°·00
Kew-Correction	—·28
Corrected Temperature ...	18·72
By Air-Thermometer	18·70

No. 3. DETERMINATION OF THE COEFFICIENT OF EXPANSION OF GLASS BY MEANS OF THE WEIGHT THERMOMETER.

THE apparatus consists of a small glass flask[1] (Fig. 1) of from 20 cc. to 25 cc. capacity. The neck of the flask is drawn out so as to terminate in a moderately fine tubulure. A portion of the glass *a* at the bottom of the neck is ground, so that the tube *b* which surrounds the neck may fit securely.

Fig. I.

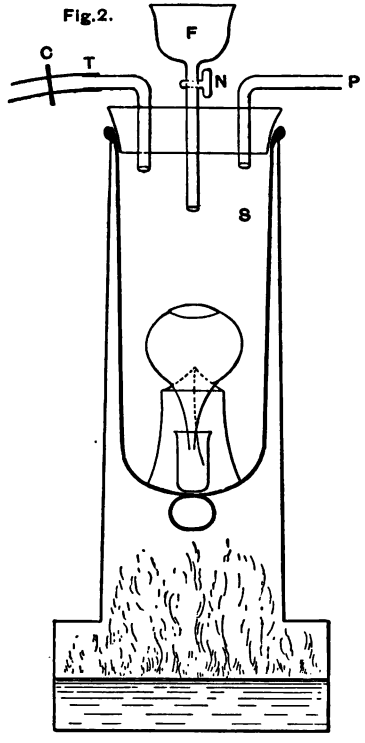


The first thing to be done is to thoroughly clean the flask, by successive rinsings with nitric acid, potash, and water. The flask is gently heated over a flame, and then the neck is quickly immersed in nitric acid. As the flask cools the nitric acid is forced into it by atmospheric pressure. In order to get the acid out again the apparatus figured below (Fig. 2) must be used. It consists of a narrow glass bell-jar, *S*, cylindrical in shape, and closed at the top by a well-fitting caoutchouc cork. The latter is perforated in three places, so as to allow of the passage of two bent tubes *T* and *P*, and also of a funnel *F*, the latter provided with a glass tap *N*. A thick-walled india-rubber tube connects *P* with a Geissler water-pump; *T* is also fitted

[1] Supplied by Cetti, 36, Brooke Street, Holborn, E.C.

with a similar tube, which for the nonce is closed by a clamp *C*. Inside the glass cylinder is a small tripod, which supports the

Fig.2.



flask in the manner indicated. On producing a vacuum in the cylinder *S*, the acid is forced out into the beaker. The flask is filled with potash by means of the same apparatus; the neck of the flask being allowed to dip under the surface of a solution of potash contained in a beaker. And so with the washing with water, which latter operation must be repeated several times. The flask must then be dried. To this intent the tube *T* is made to communicate with a series of *U* tubes filled with fused chloride of calcium, and *S* is surrounded by steam by placing it in a hypsometer. A vacuum is produced, the clamp *C* opened, and the apparatus allowed to fill with dry air[1]. This must be repeated many times. When the flask is dry and has

[1] It is very convenient to introduce a 3-way tap between *P* and the pump.

been weighed accurately—call its weight W—it is so placed in S that the tube of F opens into the tube b surrounding the neck. Clean and dry mercury is poured into F. When as good a vacuum as possible is attained, mercury is allowed to flow slowly into the tube b by slightly turning the tap N. By alternately letting in a small quantity of dry air, and exhausting, the flask will be almost completely filled with mercury. The jar containing the flask should be tilted while the mercury is entering to avoid the isolation of bubbles of air against the bottom or sides of the flask. A small bubble of air will of course remain in the flask, and generally shows itself at the base of the neck of the flask. When its size has been reduced as much as possible, the flask is withdrawn from S and gently heated over a sand-bath until the mercury by its expansion has expelled the bubble, and fills the whole flask. This being the case, more mercury is poured into b, so that its surface may stand considerably above c; and the flask is allowed to cool[1]. It is then placed in a funnel and surrounded by well-washed ice—care being taken the while, that the mercury never is allowed to sink below the level c. When it has been in the ice some time and been reduced to temperature zero, the tube b is lifted off for an instant, and the mercury surrounding the neck of the flask allowed to run off. The tube is then replaced, the whole apparatus lifted out of the ice, dried thoroughly and weighed accurately. This weighing gives the weight of the flask, plus the weight of mercury it contains at zero. Let it be denoted by w. The apparatus is then suspended by means of a wire cage in a hypsometer, and heated thoroughly to the temperature of the issuing steam. Call this temperature t. The apparatus is removed from the steam, the mercury which has collected in b is run off, the apparatus is thoroughly dried, allowed to cool to the temperature of the room and again weighed. Let the weight now be w'. This is evidently the weight of the flask, plus the mercury which it contains at $t°$.

[1] The appearance of mercury in contact with a perfectly clean dry glass vessel is so characteristic that it is easy to tell whether or not the flask has been properly filled.

$w - W$ = the weight of mercury in flask at 0^0,

$w' - W$ = ... at t^0,

$$\frac{w - W - \{w' - W\}}{(w' - W) \times t^0} = \left\{ \begin{array}{l} \text{apparent expansion of mercury in} \\ \text{glass per degree}^1. \end{array} \right.$$

But, expansion of glass = absolute expansion of mercury − apparent expansion, and as the absolute expansion of mercury is known from Regnault's tables[2] to be ·00018153 per degree for the temperature interval 0^0—100^0, the expansion of glass of which the flask is made can be easily found.

Weight of thermometer + mercury at 0^0 ..... = 343·235 grs.

" " ..... = 22·8815 grs.

Weight of mercury contained in thermometer at 0^0 ..... = 320·3535 grs.

Weight of thermometer + mercury at $99{\cdot}5^0$ ... = 338·3525 grs.

" " ..... = 22·8815 grs.

Weight of mercury contained in thermometer at $99{\cdot}5^0$ ..... = 315·4710 grs.

Apparent expansion of mercury per degree

$$= \frac{320{\cdot}3535 - 315{\cdot}471}{315{\cdot}471 \times 99{\cdot}5}$$

$$= {\cdot}00015554$$

Absolute expansion of mercury per degree

$$= {\cdot}00018153 \text{ (Regnault).}$$

Hence expansion of glass per degree, for temperature interval 0^0—$99{\cdot}5^0$

$$= {\cdot}00018153 - {\cdot}00015554$$

$$= {\cdot}00002599.$$

D. J. CARNEGIE.

[1] [This equation neglects a small fraction. The following is a strict method of deducing the coefficients of expansion.

Let X = weight of mercury in the flask volume V at 0^0,

X' = ... V' at t^0,

ρ, ρ' the density of mercury at 0^0 and t^0 respectively,

α, γ the coefficients of expansion of mercury and glass;

then $$X = V\rho, \quad X' = V'\rho' = V(1+\gamma t)\frac{\rho}{1+\alpha t};$$

$$\therefore \frac{X - X'}{X'} = \frac{(\alpha - \gamma)t}{1+\gamma t}.$$

In the text $1+\gamma t$ is regarded as being equal to unity.]

[2] Regnault's observations have been re-calculated by Wüllner (*Pogg. Ann.* CLIII., p. 440) with the result of giving ·00018163 the mean coefficient of absolute expansion of mercury between 0^0 and 100^0.

The observations made are included in the following Table:

Weight of empty bottle.	Weight with mercury at 0°.	Weight with mercury at boiling point.	Barometer.	Coefficient of relative expansion.	Expansion of glass.	Corrected result (Wüllner, see note).	Observer.
12·7475*	353·0320	335·1275	(B. P. 100·525)	·0001536	·0000279	·0000289	W. H.
22·888 (No. 1)	343·218	338·366	30·168 in.	·0001546	·0000269	·0000279	G. B.
25·3140 (No. 2)	376·3275	370·9352	29·700 „	·0001560	·0000255	·0000265	A. S. E.
25·317 (No. 2)	376·343	370·899	772·15 mm.		·0000246	·0000256	I. F.
22·882	343·2335	338·317	30·342 in.	·0001529	·0000258	·0000268	F. M. P.
22·8815	343·235	338·3525	(B. P. 99°·5)	·0001555	·0000259	·0000269	D. J. C.

* An ordinary specific gravity bottle.

No. 5. MATTHIESSEN'S METHOD FOR THE DETERMINATION OF THE DENSITY OF WATER AT DIFFERENT TEMPERATURES.

THIS method consists in determining the loss of weight in water at different temperatures of a piece of glass whose mass is known. Supposing we know the rate of expansion of the glass we can thus calculate the expansion of the water.

If the glass for instance were first weighed in water at its point of maximum density and the water were then heated, the apparent weight of the glass would be found to increase. If for a moment the expansion of the glass were neglected this increase would be due to the fact that, the density of the water being less, the volume of the water which the glass displaces would have less weight, and thus a smaller fraction of the weight of the glass would be supported by the upward thrust of the water. The fact that the glass also expands tends to diminish this apparent increase of weight because it increases the volume of the water displaced. By means of the weighings we find the actual increase of the apparent weight, which is due to the excess of the effect of the expansion of water over the effect of the expansion of glass. We know already the expansion of the glass and so also its effect, and can thus find at once what is the effect of the expansion of water alone.

The reason for selecting glass for this purpose is that its expansion is very small, and thus any error in its actual value would have little effect on the accuracy of our results. It is

obvious that if we suppose the law of expansion of water known the same method enables us to find the expansion of glass or any other substance not affected by water.

For a complete explanation of the theory see the paper by Matthiessen in the *Philosophical Transactions*, 1866. See also Balfour Stewart's *Heat*.

The following is a short description and explanation of the method employed in the Cavendish Laboratory.

We shall first describe the apparatus employed there.

To begin with we have an accurate balance capable of weighing to milligrammes. This balance is supported on a shelf which is attached to a chimney. One of the scale-pans is removed, and to the arm is attached a fine German-silver wire. A piece of this wire at the lower end, part of which is always immersed in the water in which the weighing takes place, is considerably finer than the rest, being only ·004 of an inch in diameter. The wire is led through a hole in the floor of the balance, continued through the shelf on which the balance stands. To the end of the wire is attached, by means of a groove near one end, the piece of glass whose weight in water is to be determined. This piece of glass is of a cylindrical form, its length being large compared with its diameter. The length of the wire is such that when the arm of the balance is horizontal and weighing is going on the piece of glass does not touch the bottom of the vessel containing the water in which it is weighed. This vessel is a glass cylinder, whose height is such that when it is nearly full of water the swinging of the balance will not pull any part of the piece of glass above the surface of the water; while at the same time only a very short length of the German-silver wire is immersed. This glass cylinder is placed inside a jacketed copper vessel. The interior of the copper vessel is filled with water to such a height as to immerse the glass cylinder as far as may safely be done without risking its being floated about. Water is also put inside the jacket of the copper vessel, which is in shape cylindrical, and is provided with a lid. The lid consists of two semicircular separate pieces, which can be put off or on at pleasure. They also are jacketed, and can by means of tubing have their

interiors connected with the jacket of the copper cylinder, so that any steam formed in it can circulate also through them. When both put on, the semicircular pieces completely close in the copper vessel, save for three holes, half of each hole belonging to each semicircular piece.

The central hole is that through which hangs the German-silver wire with its attached piece of glass. This hole is large enough to permit of its also being the means of enabling a thermometer to have its bulb immersed in the water contained in the glass cylinder while its stem projects through the lid. The thermometer is supported on a stand placed on one of the halves of the lid, and it is fixed in the stand so that its bulb is at the same level as the piece of glass immersed in the water; care being taken that the German-silver wire is quite free of the thermometer stem, of the stand supporting it, and also of the circumference of the hole.

The thermometer stem should be long enough to permit of the head of the mercury column being above the lid, while its bulb is immersed, at the various temperatures of the experiment; for it is not desirable to remove the lid more often than necessary, lest particles of dust should find their way into the water and cling to the piece of glass, altering also the temperature. Thus if the range of temperature is to be great it is best to employ two thermometers, the one for the low temperatures, the other for the high. The former of course is removed when it is found desirable, and the latter is substituted. This also obviates the evil of having a long thread of mercury in the thermometer, at an uncertain temperature, above the lid of the copper vessel, and so causing an error in the temperature readings. While if during a considerable range of temperature the head of the mercury column were below the lid there would be a continual source of error, owing to its not being possible to get the eye to the same level as the head of the mercury column without pulling the bulb of the thermometer out of the water. The actual zeros of the thermometers have been determined and their errors are known.

Of the two remaining holes in the lids, the one is for the handle of a stirrer, which carries a flat metal plate of the shape

of a crescent, which is used to stir the water surrounding the glass cylinder. The shape is such that it covers a considerable area near the glass cylinder, and so can keep the temperature of the surrounding water very uniform without any risk of its coming against the cylinder itself, which would be apt to cause the cylinder to float. This hole may also be used for enabling the water inside the glass cylinder to be stirred by a long glass rod.

The object of the third hole is to permit the steam formed inside the copper vessel to escape. It is provided with a chimney, formed of a bent tube, which is moveable and can be placed so as accurately to cover the hole. The other end of the tube is bent so as to pass into the chimney behind the balance-shelf. The only communication between the interior of the chimney and the outside is by a small hole made in a moveable wooden door which accurately fits the fireplace. It is through this small hole that the bent tube from the copper vessel passes. The chimney has a good draught, increased by means of a gas jet, and so carries off the steam which otherwise might condense on the part of the German-silver wire above the copper vessel, and so vitiate the weighings.

The copper vessel is heated from below by one or more Bunsen burners supplied with gas from the nearest main. The supply of gas may be regulated so as to cause the temperature to rise uniformly or to remain sensibly constant as the experimenter chooses.

A further requisite is a clean glass rod with which to remove any bubbles that may be formed in the glass cylinder and cling to the piece of glass. Unless the light be very good it is also desirable to have a lamp which may throw a strong light when required inside the copper vessel, so that the experimenter before weighing may be certain there are no bubbles left. The lamp and the stand for the thermometer are placed on the one half of the lid of the copper vessel, which half need never be moved. The other half should be removed as seldom as possible. There need be no occasion for doing so except immediately before each weighing when bubbles are to be looked for.

Method of conducting the experiment.

Take as much distilled water as may be required and boil it thoroughly, keeping it boiling for some time, say 15 or 20 minutes. It may then be cooled to the temperature of the room by surrounding the containing vessel with cold water. The glass cylinder in which the piece of glass is to be weighed is then filled with the water to the desired height. Some of the water should remain over, and may be used if required to supply the place of the water lost through the steam arising from the glass cylinder during the heating process.

Supposing the copper vessel supplied with the proper amount of water and the stirrer, thermometer, &c. in their proper places the experiment may then begin.

For some time before each observation the stirrer is to be employed, care being taken not to make the water in the copper vessel splash over into the glass cylinder. When the thermometer indicates the temperature at which an observation is to be made the supply of gas may be regulated so as to keep the temperature fairly constant. The piece of glass is then examined for bubbles; these being removed and the half lid at once replaced an accurate weighing is made. This determines the excess of the weight of the piece of glass over that of the water displaced. Since the variation in this excess is very small it is only a question of finding how many milligrammes or centigrammes, as the case may be, must be added to an already known weight. Thus the observation may be made rapidly, which is of importance, especially at high temperatures, when there is more risk of bubbles attaching themselves to the glass. It also diminishes any error that might arise from a variation in the temperature.

The expansion of glass may for our present purpose be determined with sufficient accuracy by the following method. A rod of glass of about 50 centimetres long is placed inside a glass-tube of somewhat greater length, and of 4 or 5 cm. bore. There are two scratches on the glass rod, perpendicular to its length near the ends. The rod rests on two pieces of cork, so that the scratches are on its upper surface. The ends of the glass-tube

are closed by corks, through each of which is passed a small piece of glass-tubing and also a thermometer. One of these pieces of glass-tubing is connected with a boiler, from which steam can be passed into the tube, the other piece communicates with a condenser. By means of the steam the glass rod may be heated to a determinate temperature. The expansion of the rod between the initial temperature and the final is found by means of two reading microscopes, one for observing the position of each of the two scratches on the rod. By means of these we can find the increase of the distance between the two scratches, and by means of a centimetre scale determine the initial distance. The linear expansion for one degree of temperature may then be calculated, since the whole rise in temperature is known; and the cubical expansion may be taken as three times the linear.

For a full account of the method see Glazebrook and Shaw's *Practical Physics*, § 36.

The following is a statement of some of the results obtained:

Weight of piece of glass in air 18·648 grammes.

Coefficient of cubical expansion of glass taken as ·0000237.

I.

Corrected temperature.	Weight of glass in water.	Loss of weight in water.	Density of water after making correction for the expansion of glass.
10	9·129	9·519	·99974
20	9·139	9·509	·99845
30	9·153	9·495	·99676
40	9·174	9·474	·99431
50	9·229	9·419	·98828
60	9·256	9·392	·98521
65	9·295	9·353	·98100
75	9·354	9·294	·97456
85	9·401	9·247	·96940
94	9·437	9·211	·96528

The lowest temperature of observation being 10°, the density there has been in the above calculation assumed to be ·99974.

II.

Corrected temperature.	Weight of glass in water.	Loss of weight in water.	Density of water after making correction for the expansion of glass.
	grammes.	grammes.	
18	9·135	9·513	·99897
22	9·14	9·508	·99831
24	9·145	9·503	·99773
26	9·15	9·498	·99715
28	9·155	9·493	·99658
31	9·16	9·488	·99600
34·5	9·17	9·478	·99485
37·5	9·175	9·473	·99442
43	9·2	9·448	·99150
54	9·225	9·423	·98862
60	9·25	9·398	·98585
70	9·32	9·328	·97826

III.

Corrected temperature.	Weight of glass in water.	Loss of weight in water.	Density of water after making correction for the expansion of glass.
	grammes.	grammes.	
16·2	9·132	9·516	·99927
23·2	9·143	9·505	·99795
34·7	9·164	9·484	·99601
38	9·195	9·453	·99215
47·8	9·215	9·433	·98981
61·4	9·287	9·361	·98192
74·5	9·352	9·296	·97480
93·4	9·449	9·199	·96416

SUMMARY.

Corrected temperature.	Density of water corrected for expansion of glass.	Observer.	Corrected temperature.	Density of water corrected for expansion of glass.	Observer.
10	·99974	J. T. K.	40	·99431	J. T. K.
16·2	·99927	G. B.	43	·99150	C. C.
18	·99897	C. C.	47·8	·98981	I. F.
20	·99845	J. T. K.	50	·98828	J. T. K.
22	·99831	C. C.	54	·98862	C. C.
23·2	·99795	G. B.	60	·98521	J. T. K.
24	·99773	C. C.	60	·98585	C. C.
26	·99715	C. C.	61·4	·98192	I. F.
28	·99658	C. C.	65	·98100	J. T. K.
30	·99676	J. T. K.	70	·97826	C. C.
31	·99600	C. C.	74·5	·97480	I. F.
34·5	·99485	C. C.	75	·97456	J. T. K.
34·7	·99601	G. B.	85	·96940	J. T. K.
37·5	·99442	C. C.	93·4	·96416	I. F.
38	·99215	I. F.	94	·96528	J. T. K.

C. CHREE.

No. 7. DETERMINATION OF THE POINT OF MAXIMUM DENSITY OF WATER. JOULE'S METHOD.

WATER and liquids the chief constituent of which is water differ from all other liquids in having a point of maximum density, that is, a temperature such that both cooling and heating therefrom produce change of volume in the same direction, namely dilatation. The point of maximum density of water having been chosen as the standard for comparison of densities, the exact determination of the temperature at which this point is reached becomes of great practical importance. Many different experiments have been made for this purpose, and the results obtained by different methods agree fairly well amongst themselves. The different methods employed can be divided into two main classes.

1. An accurate knowledge of the coefficient of expansion of some solid is necessary.

a. The indications of a water thermometer are compared with those of a mercury thermometer (Delie and Dalton's method).

b. A solid is weighed in water and the temperature determined at which the loss in weight is greatest (Hallström's method).

c. The variation in weight of a quantity of water filling the same vessel at different temperatures is determined (Blagden and Gilpin's method).

2. The change in density is determined by the convection currents produced.

a. A thermometer inserted near the bottom of a tall cylindrical vessel filled with water and cooled in the middle part by some surrounding ice will after some time indicate a stationary temperature, which will be approximately that of the maximum density. (Hope's method.)

b. Joule and Playfair's experiment for determining the point of maximum density of water is also based on this second general method. They devised an apparatus and a mode of working which greatly improved on Hope's and gave means of attaining the utmost accuracy. The velocity of the convection currents set up in two tall cylinders communicating with each other by two channels, one at the top and one at the bottom, when filled with water and kept at different temperatures was measured. A glass float is put into the channel at the top, and the velocity of the current is measured by the motion of this float relative to a scale fixed at the back. A set of values for the velocity of the current was thus obtained, the mean temperature of the two vessels being different, and chosen so that in at least one case the current went in the opposite direction from that in the others. With these values a curve was constructed, from which the mean temperature at which the velocity of the current would be zero can be deduced. This is the temperature of maximum density. A description of the apparatus used, the mode of working and the results obtained, will be found in the paper by Joule and Playfair, *Phil. Mag.*, series 3, vol. XXX. page 41.

The apparatus used in the Cavendish Laboratory for determining the point of maximum density of water by this method is constructed on the same principle as that originally used by Joule and Playfair, and has also the same dimensions. To guard against rapid changes of temperature from outside it is wrapped round with hemp. A small tube runs down along the side of each vessel, with which it communicates through some holes. Thermometers graduated to $\frac{1}{5}$ degree Centigrade and reading with accuracy to $\frac{1}{20}$ are suspended in these tubes by means of strings. The freezing points of these thermometers were re-determined, and a suitable correction for the zero reading applied to each reading taken.

Joule's original method of working is slightly modified, as instead of measuring the velocity of the current produced, the temperatures are so adjusted that no current is produced on making communication at the top and bottom between the two vessels. The water in the two vessels must then clearly have the same density, and the mean temperature of the two will give the point of maximum density. The assumption made here is, that the mean coefficient of expansion in the range of temperature taken above and below the point of maximum density is the same. To ascertain the presence and direction, or absence of a convection current the following plan of working is adopted. The water is well stirred, the slide at the top opened to allow the two levels to equalise themselves, then shut again and the water stirred again. An exact reading of the temperature in each vessel is then taken, the stopcock in the lower channel opened, the slide at the top carefully removed, the float put into the middle of the top channel and its motion watched.

The experiment was carried on at the ordinary temperature of the laboratory (about 16° C.) and the water cooled by putting ice into it till the temperature of the one was somewhat above, that of the other below 4° C. Care had to be taken not to make any observations before all the ice was melted, as otherwise on opening the slide at the top local currents would have been set up there, which might altogether have hidden the effect of those looked for. For the same reason the water must always be kept well stirred. A movement of the glass float at the top on opening the stopcock and slide indicated by its direction in which of the two vessels the water is denser, the direction of the convection current being from denser to lighter in the lower channel, from lighter to denser in the upper channel. By either increasing or decreasing the density of the water in one side, two temperatures can be obtained at which the density is the same. The change in density is effected by either using some ice or some warm water. According as to whether the water is above or below its temperature of maximum density the change in density produced by cooling or warming is reversed.

The best way of working in carrying out the experiment is to lower the temperature of the water in one vessel to near the freezing point, and then to adjust that in the other to a temperature such that no current is produced. The temperature of the colder water is then allowed to rise slowly by taking in heat from the surrounding air, and that of the other is cooled by ice. Another value for two temperatures, at which the density is the same, is thus obtained, these two last being nearer together; the process is repeated and a set of values nearer and nearer to each other is got. The mean temperature of the two vessels is taken in each case as that of the maximum density.

Some of the results obtained by this method are:

I.

	Temperature of A (thermometer No. 34, F. P. reading = +·1).		Temperature of B (thermometer No. 34, F. P. reading = +·05).		Mean temperature.
	Observed temp.	Corrected reading.	Observed temp.	Corrected reading.	
1.		6·2		2·4	4·3
2.		5·9		2·6	4·25
3.		6·0		2·7	4·35

Temperature of maximum density (mean of 3) = 4·30.

(J. T. K.)

II.

	Temperature of A (thermometer No. 34, F. P. reading = +·1).		Temperature of B (thermometer No. 34, F. P. reading = +·05).		Mean temperature.
	Observed temp.	Corrected reading.	Observed temp.	Corrected reading.	
1.	7·4	7·3	1·2	1·15	4·23
2.	6·8	6·7	1·9	1·85	4·28
3.	6·4	6·3	2·2	2·15	4·23

Temperature of maximum density (mean of 3) = 4·25.

This value is somewhat too high, and the error can at least in part be accounted for by the following two circumstances:

(1) The water used was not pure. There was a great deal of iron-rust in suspension, and it probably contained also some impurities in solution.

(2) The sensitiveness was not sufficiently great, as was shewn by a separate experiment undertaken for the purpose of determining the degree of sensitiveness. This consisted in ascertaining the least difference in temperature which would give a current noticeable by the motion of the bead. The result obtained was that at 10·8° a difference of temperature of 0·2° between the two vessels produced a decided current. This corresponds to a difference of density which at 4° is only attained by a difference of temperature of about 0·4°C. The limit of error is therefore 0·4°C., a value much larger than what it ought to be.

IDA FREUND.

No. 8. ON THE MANUFACTURE OF AN AIR THERMOMETER FOR RAPIDLY INDICATING COMPARATIVELY HIGH TEMPERATURES[1].

A LONG, uniform glass tube has a bulb blown near to one extremity, both ends being left open, and is bent round at right angles to itself at a distance of about two or three inches from the commencement of the bulb.

It is first carefully cleaned, by connecting the long end with the aspirating pump, and drawing consecutively acids and potash

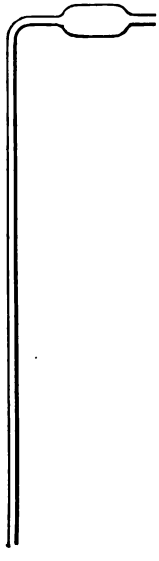


Fig. 3.

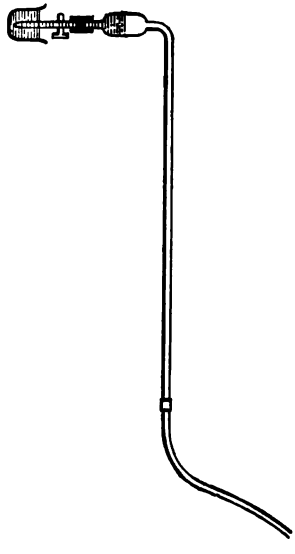


Fig. 4.

into the bulb, and then allowing them to run down the tube, afterwards well washing with spring water and distilled water.

When this operation is complete, the free end is connected with a series of calcium chloride tubes, and air is passed through,

[1] Compare Berthelot's instrument.

while the bulb and the tube are warmed with a spirit lamp to facilitate the drying.

As soon as it is completely dry, the drying tubes are removed, and a small glass tap is connected with the open end of the bulb by a short piece of india-rubber tubing, which has been previously well washed and dried.

The lower end of the tap is introduced into a small beaker of pure, dry mercury (at a known temperature), and the pump being again put in action, the small tap is slightly turned, and the mercury allowed to ascend slowly into the bulb. As soon as it reaches the neck of the bulb the tap is shut off, and the thermometer disconnected from the pump by slipping off the connecting tube.

The beaker is now removed, and a second beaker, whose weight has been previously determined, is placed under the tap, which is turned on, and the mercury allowed to sink through the whole length of the bulb, being stopped at exactly the point at which it is intended to seal off the bulb. The quantity of mercury that has fallen through is weighed, and thus we determine the weight of mercury at the temperature of the experiment, which is required to fill the bulb, and hence deduce the volume of the bulb.

To find the volume of any length of the tube, the bulb end of the instrument is connected with the air-pump, and the tap fastened on to the other end. When a sufficient length of mercury has run in the tap is turned off. After the length of the column introduced has been measured off, by placing the stem of the thermometer over a scale (the reading of which may be afterwards corrected with the beam-compass), it is dropped into a beaker and weighed as before.

The cleaning and drying processes have now to be repeated —with the utmost care[1]. The instrument should first be well washed with nitric acid, to remove any small particles of mercury which may have adhered to the inside.

In drying, the air is caused to pass first through calcium chloride, and then through phosphoric pentoxide tubes. This

[1] The facility of motion of mercury in a narrow glass tube depends very greatly upon the glass being perfectly clean and dry.

operation must be allowed to go on for a considerable time, and meanwhile the bulb and tube be thoroughly heated.

Two little stoppers, each consisting of a short piece of india-rubber tubing, having one end closed with a small glass rod, are got ready, and as soon as the thermometer is perfectly dry, it is disconnected from the pump and drying tubes, and a stopper is put on to each end.

The end of the bulb is now sealed up. The instrument is mounted vertically on a stand, with a scale alongside the stem

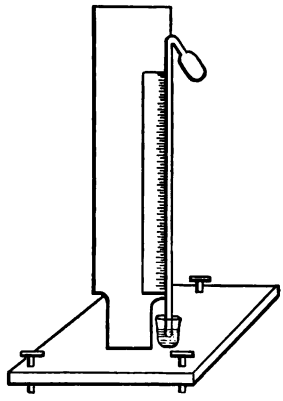


Fig. 5.

(for convenience in determining the boiling point, and the melting point of ice, the arm holding the bulb is bent down to an angle of about 45° with the stem). A small beaker of pure mercury is put underneath, and the stopper withdrawn from the end of the tube, beneath the surface of the mercury.

The bulb is heated in a large Bunsen flame till it begins to get red—on allowing to cool the mercury rises in the stem. The instrument is thus filled with air which is under a pressure nearly equal to that of the atmosphere at the highest temperature for which it can be used, but at ordinary temperatures the pressure is of course smaller. Before graduating the instrument, a diamond scratch is made upon the stem as a reference mark.

The temperatures 0° and 100° C. are obtained by putting the bulb in a funnel of melting ice and in a steam jacket.

The height of the barometer and the temperature of the room are observed at the time of the determination.

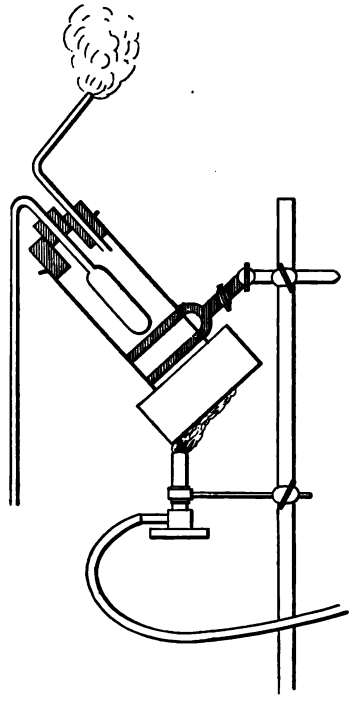


Fig. 6.

A tube is used to allow the steam to escape—it should issue very gently.

Observations for graduation:

Wt. of mercury which fills the bulb at 15° = 113·460,

Vol. of 113·46 grms. Hg at 0° = 8·345 c. c.,

∴ at 15° C. = **8.368** c. c.

Length of column introduced into tube = 28·15,

Weight of this = 5·8055,

∴ wt. of 1 cm. = ·2062 at 15° C.

= ·2067 at 0° C.

∴ vol. of 1 cm. **·0152** cc.

Determination of 0° C. *and* 100° C. *points.*

(Means of several readings.)

	Barometer (corrected).	Temperature of room.	Mark on glass.	Surface of mercury.
100°C.	759·7	14·36	31·96	20·18
0°C.	755·94	16·02	31·96	31·07

F. MONTAGU-POLLOCK.

Temperatures up to the softening point of glass (about 500° C.) may be conveniently determined with very considerable accuracy by the method employed by Rudberg and Regnault to determine the coefficient of expansion of air. The method in the form it naturally takes for a class experiment consists in exposing to the source of heat a glass bulb with a neck drawn out to a fine point. The extremity of the neck must project from the hot enclosure, the rest of the instrument can be brought to the temperature it is required to measure. When this is done the extremity of the neck is sealed by a blowpipe flame and the bulb is withdrawn, allowed to cool, and weighed, let the weight be w_0. The end of the neck is then broken off under water or mercury, and the liquid allowed to enter until the pressure in the interior is equal to the atmospheric pressure. The nozzle is closed with wax while the bulb is being withdrawn from the liquid, and the bulb with the mercury or water which it contains is weighed again, taking care that the glass broken off is collected and added, let this weight be w_1. The bulb is then completely filled with the liquid and re-weighed—let this third weight be w_2.

Then, supposing that the atmospheric pressure at the time of sealing off is the same as when the nozzle is broken off under the liquid, it is evident that a volume of air corresponding to a weight $w_2 - w_1$ of the liquid has by expansion at constant pressure, namely, the atmospheric pressure, filled the bulb at the high temperature.

Its volume (not allowing for the expansion of the glass) would correspond to the weight $w_2 - w_0$ of liquid, we therefore have, if θ be the unknown high temperature, and t the temperature of the air and liquid at the time of the experiment, γ the coefficient of expansion of glass

$$\frac{(w_2 - w_0)(1 + \gamma\theta)}{1 + \gamma t} = \frac{(w_2 - w_1)(1 + \alpha\theta)}{1 + \alpha t},$$

when α is the coefficient of expansion of air at constant pressure.

This plan of measuring temperature works very well in practice. It is of course necessary that the bulb should be very thoroughly dried before being used. The precautions described by Regnault (*Mém. de l'Inst.* T. XXI.) are in general unnecessary unless extreme accuracy is required. Some results obtained by various observers with this method are appended.

(W. N. S.).

TABLE OF RESULTS.

Kind of Bulb and Source of Heat.	Weight of empty bulb.	Weight of bulb partially filled.	Weight of filled bulb.	Temp. of liquid.	Calculated temp. of source.	Observer.
Soft glass in Bunsen Flame.	6·5805	14·415	19·713	13°·6	457°C.[1]	F.M.P.
,,	6·191	14·199	18·469	16°	531°	I.F.
Hard glass in Bunsen Flame.	24·335	33·514	38·4174	22°	607°·2	G.H.D.[2]
Paraffin bath at 200° C. by Mercury Thermom.	4·589	8·434	14·308	13°	201°	A.S.E.
,, at 197° C.	4·9291	9·8441	17·7256	14°	194°·8	J.T.K.

[1] The glass softened in the flame, and the bulb collapsed somewhat after sealing.

[2] July, 1886.

No. 9. AN ELECTRIC PYROMETER.

DR C. W. SIEMENS selected as the subject for his Bakerian Lecture, 1871, the effect of temperature on the resistance of metals, and a short notice of his results is given in the *Proceedings of the Royal Society*, April 1871. His experiments ranged between freezing point and 1000° C., and gave rise to an empirical[1] formula, which differed from that suggested by Dr Matthiessen, but satisfied the results of the latter observer obtained solely at lower temperatures. Siemens' formula is $R = \alpha \sqrt{t} + \beta t + \gamma$, where R is the resistance of the coil at absolute temperature t, and α, β, γ are constants, which vary for different metals. An account of the pyrometer as generally in use is given with diagrams in the *Brit. Assoc. Reports* for 1876. The resistance is measured differentially with a voltameter, and the result is easily obtained by means of a slide rule suitable for rapid and practical determinations of temperature.

A number of observations were made with an instrument supplied by Messrs Siemens, Bros., which in practice is exceedingly convenient, but in consequence of its large dimensions and the massiveness of the iron case in which it is enclosed it was not found possible to determine the constants of the instrument, and in consequence the following experiment was arranged with a view of obtaining the values of the constants for platinum.

[1] The form in which the formula is cast was suggested by a consideration of the circumstances upon which the variation of resistance is likely to depend.

To determine the temperature of a small glass cylinder in a Bunsen flame by means of an electric pyrometer.

A fine spiral wire of platinum was enclosed in a cylinder of white German glass about three inches in length. This plan was adopted because the action of the flame upon the resistance of the wire when unprotected is not yet ascertained; some previous determinations made it seem likely that this influence was very considerable. The ends of the platinum wire were passed through a screen, which secured stability, and were then connected with a Wheatstone's Bridge in order to measure the resistance. The coil was first inserted in a Bunsen flame sufficiently large to envelope the whole, and was screened from draughts of air. The glass bent under its own weight when red-hot, but the resistance became fairly constant after about a quarter of an hour, and a maximum resistance was measured.

The coil was next inserted in melting ice and also in steam at temperature 100°·6 C. Two other determinations of the resistances at higher temperatures, 154° and 202°·5, were obtained with the coil in a bath of paraffin; the former was taken so as to furnish a test equation, and was not so accurately observed as that at the higher temperature.

It has been observed[1] that wires exposed to high temperatures are liable to a variation in resistance after cooling, either of increase or decrease. In order to determine any change of this kind, the platinum spiral was again inserted in steam at temperature 100° C., an interval of three weeks having elapsed since its insertion in the Bunsen flame, and an increase of one-hundredth of an ohm was found, or a change of one in a thousand.

Temperature Determination.—The same mercury thermometer was used throughout the experiments and finally compared with an air pyrometer, and with Jolly's air thermometer. The most trustworthy result[2] gives the reading of the mercury thermometer as 2°·3 in excess of the air thermometer at 199° C., and the temperatures 154°, 202°·5 must therefore be corrected to 152° and 200°·2 C. This result agrees satisfactorily with that

[1] *Brit. Assoc. Reports*, 1876. [2] See p. 11.

obtained by calibrating the mercury thermometer and applying Regnault's corrections approximately[1]. The reading of a mercury thermometer exceeds that of an air thermometer at 200°C. by an amount varying from one to five degrees, depending on the kind of glass used in manufacture. In this case the calibration error amounted to 5° in excess at 208° C., and the mercury thermometer probably reads 2° or 3° higher than the air thermometer at this temperature. Thus, if both were accurately calibrated, the corrected value of 202°·5 is from 199°·5 to 200°·5; and the experiment with Jolly's air thermometer gave 200°·3 C.

Values of the Constants.—The values of α, β, γ as found by Dr Siemens are 0·03937, 0·002164, and −0·2413, where it is to be observed that γ is negative. The values obtained by these experiments are −·0023, ·001456, and ·5905, where α is negative and γ is positive. Although these are entirely different from those obtained by Siemens, they satisfy the test equation within the limits of the combined errors of observation and variation of resistance, namely, one-hundredth of an ohm. It was afterwards found that a small hole was fused in the glass cylinder by the Bunsen flame, and that paraffin had entered and surrounded the wire, but apparently without vitiating the results. A possible source of slight error is the fact that red-hot glass ceases to be a non-conductor and a correction may be necessary for the resistance in the Bunsen flame[2]. The values of the constants without applying corrections for the mercury thermometer are

$$\alpha = \cdot 004807, \quad \beta = \cdot 001257, \quad \gamma = \cdot 5274,$$

which agree more nearly with those given by Siemens than the values finally obtained.

The uncorrected temperature obtained is 986° C., whilst the corrected value is 941° C.[3]. This result might be compared

[1] *Mémoires de l'Académie*, Tom. XXI.

[2] Glass conducts as an electrolyte at a temperature below that of fusion. *Encycl. Brit.*, Art. Electrolysis. Buff. *Ann. de Chimie* (3) XLII. p. 125, 1854, gives results for the resistance between the interior and exterior of a tube of glass. Its effects in this case would be inappreciable.

[3] [This result is very much too high. Siemens' constants give the value about

with those obtained by means of Favre and Silbermann's calorimeter[1]. Although the difference in the results is large, it must be remembered that the experiments with the calorimeter were to determine the temperature of a small piece of metal after being cooled by a fall of a foot through the air, and the loss of heat from a small piece of metal must be very great under such circumstances.

Results.

Temp. Cent.....	0°	100°·6	152°	200°·3	$t°$
Resistance in ohms ...	·95	1·09	1·15	1·23	2·28

The values of the constants are determined from the first, third, and fourth columns, and when supplied in the equation formed from the data of the third, give the resistance as 1·16 ohms. Thus the difference is within the limits of the observation errors.

The final equation is

$$2{\cdot}28 = -{\cdot}0023\sqrt{t} + {\cdot}001456t + {\cdot}5905,$$

and the value of the temperature of the glass in the Bunsen flame is 941° C.

A. S. Eve.

470° C. for the temperature, which is probably not far from right. As a matter of fact the curve representing the variation of resistance of platinum with variation of temperature is very nearly a straight line, and the results obtained by assuming Siemens' formula and determining the constants by observations at comparatively low temperatures may be very wide of the truth in consequence of small experimental errors. This subject has been lately taken up and worked out in the laboratory by Mr H. L. Callendar, of Trinity College. W. N. S.]

[1] See p. 57.

No. 10. LAPLACE AND LAVOISIER'S ICE-CALORIMETER USED FOR MEASURING THE HEAT GENERATED IN AN INCANDESCENT ELECTRIC LAMP.

BLACK, who discovered and investigated the phenomena of latent heat and specific heat, introduced also the two most important methods for measuring quantities of heat. The effects of heat on bodies, on which these methods are based, are:

1. Rise of temperature,
2. Change of state.

In applying the second method he determined the amount of heat lost by a known mass of the body examined in cooling through a certain range of temperature, or, in changing its state, by the amount of ice converted by it into water at the same temperature as the ice.

For this purpose he used a clear transparent block of ice in which a hole had been made and which could be covered over with another flat piece of ice. The body to be examined was then introduced into the cavity, which had previously been carefully dried, and left there till it had come into thermal equilibrium with the ice. No communication of heat from outside could take place, as the only effect produced by the heat of the surrounding atmosphere is to melt some of the ice on the outer surface of the block.

Laplace and Lavoisier made use of the same method for measuring quantities of heat, but they somewhat modified the working of it. A description of the apparatus employed by them and of the experimental details will be found in *Oeuvres de Lavoisier*, Vol. II. p. 283, or in *Mémoires de l'Académie des Sciences*, 1780. This modification of Black's original process does away with the necessity of procuring a perfectly clear block of ice of suitable size, which is not always easy, but on the other hand some sources of error are introduced, from which the first is free.

The advantages and disadvantages of the method in general can be summed up in the following way.

Its advantages are:

1. The quantity of ice melted is a very precise measure of the quantity of heat employed to produce this effect.

2. No heat is lost by conduction or radiation to a surrounding vessel and the atmosphere.

3. There is at most only one measurement of temperature necessary.

Its disadvantages are:

1. The latent heat of ice is very great, so that unless the amount of heat to be measured is great the quantity of ice melted will be small, and any slight error in the estimation of the water produced will introduce a comparatively great error into the final result.

2. There are two inevitable sources of error:

I. Some water always adheres to the surface of the ice. This is the case at the beginning and end of the experiment, and if these quantities of water were the same in both cases the amount of water collected would not be influenced by it. This depends however entirely on the relative arrangement and on the surface of the pieces of ice, and since, owing to the melting of some of it, both these conditions vary during the course of the experiment, the amount of water retained at the end will probably not be the same as that retained at the beginning. It is impossible to compensate for this error.

II. Conduction of heat from outside takes place. Since the air contained in the vessel is at temperature zero, it will in general be denser than that of the surrounding atmosphere. When the tap which lets off the water is opened this air sinks together with it and its place is taken by some fresh air entering through the lid at the top. This air has to pass through the exterior layer of ice where it is cooled. If however the change takes place quickly it cannot be prevented from carrying some of its heat on to the ice in the middle vessel, thus increasing the amount of water melted and making the final result larger than what it ought to be. Some conduction also takes place through the material of the tap leading to the

inner vessel. The greater the excess of temperature of the surrounding air over that of the freezing point, the more sensible does this error due to conduction from outside become. It can however be corrected for by taking "the rate of drip," that is determining the amount of water melted during a certain interval of time when the calorimeter is left to itself, without any hot body in it. From a knowledge of the rate of drip and the time during which the real experiment lasted, the amount of ice melted during this time owing to conduction from outside can be calculated, and this value has to be subtracted from the total amount of water formed.

It follows from these considerations that this method can only be advantageously used for measuring large quantities of heat which are sufficient to melt a considerable quantity of ice. In this case the water adhering to the surface of the ice will only form a small fraction of the total weight of water collected, and this error will therefore not materially affect the result.

In the following experiments to be described the ice-calorimeter was used to measure directly the heat generated in an incandescent electric lamp. The current running through the lamp was measured absolutely, and from the two values thus obtained, namely, (1) The heat generated in unit of time by the current, (2) The strength of the current, the resistance of the heated lamp was calculated.

The arrangement made in carrying out the experiment was the following:

A calorimeter like that described by Laplace and Lavoisier, consisting of three concentric copper vessels, was used. The inner and middle vessel have very tightly shutting lids. The wires leading to the lamp contained in the inner vessel pass through the middle of the first lid and then through narrow tubes going vertically upwards through the middle of the second[1]. These tubes reach to just above the height of the outer vessel. The whole calorimeter is enclosed in a wooden

[1] It would appear from the observations that some conduction of heat took place along these copper tubes, and it would therefore be advisable to modify this arrangement in future experiments.

box, the space between the two being tightly packed with kieselguhr. The two taps at the bottom and the end of the tubes carrying the connecting wires at the top are wrapped round with cotton wool so as to reduce the conduction from outside to a minimum. This was done with such good success that on one occasion when the day was cold, the tap leading to the inner vessel was left open for about twenty minutes and only two or three drops of water escaped, whilst the melting of the ice in the outer vessel was very slow also. When the apparatus had been filled with well-washed small pieces of ice, it was left for some time with both taps open for the ice to get well drained and for the apparatus and lamp to come into thermal equilibrium with it. As soon as one felt sure that both these conditions were fulfilled the rate of drip was taken. Ten or fifteen minutes are in general a sufficiently long time for collecting the water due to melting by the heat conducted from outside, but this depends of course on the actual amount of drip. The wires leading to the lamp were then connected, through a key and some arrangement for measuring the current absolutely, with the source of the electromotive force. The lamps used in the experiment were either 20 volt or 55 volt lamps. In working with the 20 volt lamp a secondary battery was used for giving the electromotive force, whilst in the case of the 55 volt lamp this was supplied from a dynamo-machine. The current was measured by the amount of copper deposited on the kathode of a copper-sulphate cell, in some cases also by the deflections of a Helmholtz tangent galvanometer or a Thomson's graded galvanometer. The current was allowed to run for an hour in the case of the 20 volt lamp, for half an hour in that of the 55 volt lamp. It took a considerable time for the lamp to be entirely cooled down and for the ice to drain after the circuit had been broken, and to make sure that this point had been reached the rate of drip was taken again at the end of the experiment and its value compared with what it was at the beginning. The two ought to be identical.

If W is the weight in grams of water collected in t' seconds, the current having been on for t seconds, and w is the rate of drip per second, then the heat generated in time t in the

lamp is

$$H = (W - wt')\,79{\cdot}25,$$

where 79·25 is the value taken for the latent heat of ice.

Also if γ is the current, R the resistance of the heated lamp,

$$H = \frac{\gamma^2 . t . R}{J},$$

from which it follows that

$$R = \frac{HJ}{\gamma^2 t}.$$

Substituting the value for H into this equation it becomes

$$R = \frac{(W - wt')\,79{\cdot}25 . J}{\gamma^2 . t}.$$

This expresses the current and resistance in absolute units. If the ohm and ampère are used instead the value is given by

$$R = \frac{(W - wt') . 79{\cdot}25 . J}{\gamma^2 . t . 10^7}.$$

If the current is measured by electrolysis of $CuSO_4$, its strength expressed in ampères is

$$\gamma = \frac{x}{t . {\cdot}00325 . 10^{-1}},$$

where x is the amount of copper deposited in time t and ·00325[1] the electro-chemical equivalent of copper.

The results obtained by this method in five experiments were:

[1] The electro-chemical equivalent of copper as determined by the actual amount of copper deposited is not quite identical with this. Lord Rayleigh (*Phil. Trans.* 1884) gives ·2936 as the mean of three experiments to compare the equivalents of silver and copper, using platinum bowls for the deposit and a current of from $\frac{1}{3}$ to $\frac{2}{4}$ ampère. We have obtained by experiments in the Laboratory, using platinum wires to receive the deposit (the current for each wire varying from $\frac{1}{50}$th to $\frac{1}{2}$ ampère), the value 3·402 as the ratio of the electro-chemical equivalent of silver to that of copper (*Brit. Assoc. Rep.* 1886). Taking Lord Rayleigh's value of the electro-chemical equivalent of silver in C. G. S. units = ·0111794 we get the electro-chemical equivalent of copper in the same units ·003286 for the wires and ·003282 for the bowls. W. N. S.

	Lamp used.	Time current was on	Heat generated.			Water due to melting of ice by heat of lamp.	Heat generated by lamp in one second.	Current.		Resistance of lamp (in ohms).	Electromotive force (in volts).
			Time during which water was collected.	Total amount of water collected.	Rate of drip per minute.			Measured by	Strength (in ampères).		
I.											
T. C. F.		50 min.		177·2	0·384	138·8	3·66	Helmholtz' galvanometer	? ·507	60	30·3
A. S. E.		30 min.	60 min.	137·15	0·208	124·65	5·49		? ·676	50·5	34·1
II. I. F.	20 volt, two lamps connected in multiple arc	60 min.	98 min.	218·631	0·2678	192·38	4·230	Helmholtz' galvanometer	1·791	20·83	18·66
III. D. C. C.	55 volt	30 min.	75 min.	428·9	1·18		16·5779	Electrolysis of $CuSO_4$ and Thomson's graded galvanometer	1·477	32·58	48·1
IV. I. F.	55 volt	30 min.	90 min.	417·197	0·09075	409·197	17·958	Electrolysis of $CuSO_4$ and Thomson's graded galvanometer	1·542	31·71	48·7
V. I. F.	55 volt	30 min.	75 min.	424	0	424	18·6	Electrolysis of $CuSO_4$	1·634	29·28	47·9

No. 11. BUNSEN'S ICE CALORIMETER.

THIS consists of a test tube *A* (fig. 7), fused into a larger tube *B*, to which is sealed a tube *C*. The calorimeter is filled in the following manner: sufficient mercury is put in to cover the joint α (fig. 7), and enough water to prevent boiling away.

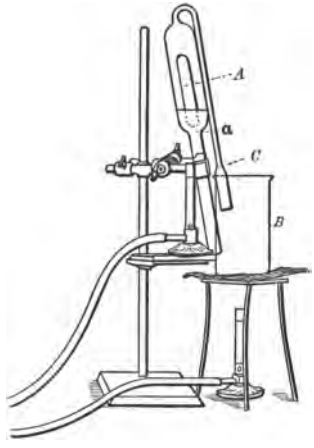


Fig. 7.

A flame is then placed under α and the open end of the calorimeter under boiling water in the beaker *B*, and the whole boiled for an hour and a half; so that the calorimeter is now full of steam. The flame at α is now drawn away, hence the boiling water is drawn up into the calorimeter. The calorimeter is then filled up with mercury; thus there can be no trace of air left in the instrument[1].

[1] The following description of the method of filling the calorimeter, taken from the Laboratory book, gives some additional details.

The calorimeter has first to be filled with *boiled* water and mercury.

For this purpose it is arranged as in the annexed sketch, the smaller tube dipping into a beaker of water kept constantly boiling. Enough mercury is introduced into the calorimeter to cover the glass joint at α (Fig. 7), then the instrument is inverted and sufficient water introduced to prevent its running dry during boiling.

It is advisable to surround the calorimeter about the point α with wire-

expelled through the tube *D*. The whole is then fitted on to a board, to keep the parts of the instrument firmly together, and is now ready for use. The position of the end of the mercury in the tube *D* is indicated by the graduations on paper fastened on the board behind the tube.

The water in the calorimeter is then frozen. To do this it is placed in melting ice to reduce its temperature to 0° C. This is then removed, and a current of cold methylated spirit is made to circulate through the test tube *A* from a freezing mixture of ice and salt.

Two vessels, *F* and *G*, surrounded by the mixture are connected to the test tube by glass and india-rubber tubing, and also to a four-way tap *K*. The tubing from the calorimeter passes to the bottoms of the vessels, the tops of the vessels are connected to the tap (fig. 8). The action of the tap is such that

of the four-way tap, *K*. When the box *F* is emptied the plug of the tap is turned through a right angle, and the exhaustion takes place in *F* while *G* becomes open to the air, and in consequence the methylated spirit flows back from *G* to *F*.

By this means if the boxes *F* and *G* are kept immersed in a *well made* freezing mixture the water in the calorimeter may be frozen until a pear-shaped mass of ice is formed round the test tube *T*. Care must be taken not to freeze so much water that the apparatus bursts.

It sometimes happens that the water refuses to freeze however long the flow of methylated spirit be continued; this may arise from the freezing mixture not being properly made and mixed.

After a convenient mass of ice has been formed the instrument is made ready for use by withdrawing all superfluous methylated spirit from *T* by means of a pipette and blotting-paper.

While the calorimeter is being used it must be kept surrounded with well washed and pounded ice to prevent any melting due to heat from the outside. It is possible that in spite of this precaution the mercury index may move, in consequence of some difference of temperature of fusion of the ice inside and outside. Any such motion should be quite regular, and may be allowed for in the observations.

The measurements may be made in two ways.

(1) The amount of heat required to move the mercury index through a definite length may be calculated from the known specific gravity of ice and the diameter of the thermometer tubing used.

(2) The instrument may be empirically graduated by using a known mass of water at a known temperature.

If solid bodies are to be dropped into the test tube *A* a plug of asbestos or cotton-wool must be first placed at the bottom of the tube, otherwise it may be broken.

air may be drawn from one vessel and supplied to the other alternately by turning it into two positions at right angles. The air is drawn through by a water-pump. In the figure air is being drawn from *F* and supplied to *G*, thus the spirit is driven from *G* to *F* through the test tube *A* of the calorimeter. When *F* is full and *G* empty, the tap is turned through a right angle, and thus air is drawn through *G* and supplied to *F*, and the current of spirit reversed. By this means, if the freezing mixture be well made up, the water round the test tube is soon frozen, and will be noticed by the mercury rushing through *D* into a beaker placed at the other end, to catch what flows over, and to prevent all the mercury rushing back into the calorimeter when the spirit is removed, before it is ready for use.

When the supply of ice is sufficient the freezing mixture is removed, and the methylated spirit drawn out of the test tube by means of a pipette and dried by blotting-paper. The calorimeter is again surrounded by melting ice to keep it at 0° C., and the beaker then removed: it is now ready for experiments.

In the experiment 10 c.c. of water at the temperature of the room was dropped into the test tube *A* to bring the position of the end of the mercury on to the scale, and the reading was then 69·9; 10 c.c. more were then dropped in from a burette (temperature 15·2 C.), the reading was 65·2. Whence we see that one division on the scale = 10 × 15·2/4·7 heat units. There were then in the calorimeter 20 c.c. of water at 0° C., and the scale reading 65·2. It was found that the motion of the mercury was so slight that it might be neglected.

One cubic centimetre of strong sulphuric acid, temperature 16·7 C., was then added, and the mercury moved 8·2 divisions along the scale, and afterwards 1 c.c. more moved mercury 6·6 divisions. The specific heat of the sulphuric acid was taken to be ·343; a correction was made for the temperature of the acid. The specific gravity was found to be 1·83, thus its percentage composition is 92 (Thorpe's *Quantitative Analysis*, p. 376). Thus the heat of combination of water and sulphuric acid was calculated, the mixtures being in the proportion of 100 parts of water to (1) 5 parts[1], (2) 10 parts[1], of sulphuric acid. The

[1] By volume.

results gave 252·6 units as the heat of combinations of 1 c.c. of acid with 20 of water, and 453·8 units as the heat of combination of 2 c.c. of acid with 20 of water. Since the water in the calorimeter is pure and air is expelled from it, the water will not freeze unless the freezing mixture is well made up, and sufficient to reduce the spirit to $-10°$ C.

In one experiment the water did not freeze, although the spirit was kept circulating through the test tube for more than an hour, and a coating of ice was formed round the outside of the calorimeter. It was then wrapped in cotton-wool to keep the heat out, the current stopped, and a thermometer placed in the test tube. It was then seen that the water had been below $-5°$ C. A series of readings were then taken, corresponding to a series of readings on the thermometer, as the calorimeter gradually heated to 0° C. A reading was also taken with the same thermometer in melting ice and at the temperature of the room.

If in filling the calorimeter it had been weighed empty, and then, when the water, and afterwards, when the mercury had been put in, it would have been easy to calculate from the results obtained the expansion of water below 0° C.

For if g, m, w be the expansions of the glass, mercury, and water, G, M, W their respective weights,

$$G \,.\, g + M \,.\, m + W \,.\, w = (G + M + W)\, k \,.\, s,$$

where k is a constant and s the difference between the readings on the scale. Then we know g and m, and we can easily find k, whence we can find w.

However, knowing four expansions, we can calculate the others.

For, if $g_1\ m_1\ w_1\ s_1\ g_2 \ldots$ be known expansions,

$$(ks_1 - g_1)\, G + (ks_1 - m_1)\, M + (ks_1 - w_1)\, W = 0,$$

and two similar equations.

Eliminating G, M and W we have

$$\begin{vmatrix} ks_1 - g_1 & ks_1 - m_1 & ks_1 - w_1 \\ ks_2 - g_2 & ks_2 - m_2 & ks_2 - w_2 \\ ks_3 - g_3 & ks_3 - m_3 & ks_3 - w_3 \end{vmatrix} = 0.$$

This is an equation to find k. Also when we know k, we have

$$\begin{vmatrix} ks_1 - g & ks - m & ks - w \\ ks_1 - g_1 & ks_1 - m_1 & ks_1 - w_1 \\ ks_2 - g_2 & ks_2 - m_2 & ks_2 - w_2 \end{vmatrix} = 0;$$

from this we can find w for the different temperatures.

A few of the readings[1] taken are:

Thermometer contained in the test tube of the calorimeter.	Corresponding reading of the scale of the calorimeter.
	°
−3·5 C.	41
−3·0 C.	32
−2·5 C.	25
−2·0 C.	18
−1·5 C.	12
−1·0 C.	6
−0·5 C.	1
0·0 C.	−2·5
In ice.	−44
At temp. of the room.	
15·2	82
15·8	100
15·9	103

Taking the expansion of glass ·000025
..... mercury ·000179

per degree of temperature, and substituting in the above equation, we obtain values for w; but the calculation is rather long, and does not give very good results. It is thought that the temperature of the mercury is not uniform throughout and the same as the water, as the mercury is heated much sooner than the water. In the instrument for this purpose it would be better to be without the tube C.

J. T. KNIGHT.

[1] These readings are interesting as giving evidence that the expansion of water is continued when the temperature is reduced below the freezing point. But as the rise of temperature was probably due in great part to conduction along the mercury, the numbers cannot be expected to give measurements of the coefficient of expansion.

No. 12. FAVRE AND SILBERMANN'S CALORIMETER.

THIS instrument, of which an account may be found in Jamin's *Cours de Physique*, Vol. II. or Witz' *Cours de Manipulations de Physique*, depends on the assumption that when a quantity of heat enters a mass of mercury the expansion is proportional to that quantity of heat. It is desirable to use as large a mass of mercury as possible, since by that means the increase in the temperature of the instrument in any one experiment may be rendered insensible. Favre and Silbermann used a calorimeter containing about 250 kilogrammes; but for laboratory models one-tenth of that quantity will suffice; the instrument here described would only hold about 16 kilogrammes.

The calorimeter used here consists of a spherical iron shell, cast in the mechanical workshop, 5 inches in diameter and $\frac{1}{4}$ inch thick. This shell is provided with three holes; into one is screwed a receiving tube of iron (like a test tube), which penetrates beyond the centre of the shell and which is only about 0·25 mm. thick, so that the hot bodies introduced may readily give up their heat to the mercury; the second hole, which is small, is the one to which the capillary reading tube is attached; this tube is sealed into a steel collar and screwed down to the shell, and it is also bent at right angles so that the part in which the expansion is measured can be placed horizontally against a millimetre scale; in the third hole a screw works, by means of which the position of the end of the mercury column can be adjusted in the reading tube[1].

[1] With this instrument it was found necessary to use a tube of small bore (about $\frac{1}{4}$ mm.). This makes it necessary to pay very great attention to the cleaning and drying of the tube, to avoid as far as possible the sticking of the mercury.

The calorimeter was filled as far as possible through the opening in which the adjusting screw works; this screw was then replaced and the whole heated to nearly 300° C., so as to drive out the air that might have been clinging to the inside of the shell; while this was going on, the filling up was completed by means of a funnel fitted into a cork and screwed down on the hole for the reading tube, which was at the highest point of the shell; when the filling was nearly completed the shell was moved about so as to dislodge any air still clinging to the adjusting screw or round the receiving tube.

The instrument was then placed in a wooden case and packed round as completely as possible with fossil meal to preserve it from change of temperature; the reading-tube was attached and adjusted to a scale. During the experiments all except the mouth of the receiving tube was covered up with tow.

In making the experiments the hot body was shot straight into the receiving tube, in which a quantity of mercury was placed, so as to conduct the heat rapidly to the sides of the receiving tube, and so into the calorimeter; but if the hot substance is one that acts on either iron or mercury, a glass test tube is inserted in the receiving tube and kept there against the buoyancy of the mercury by means of a cork collar in the mouth of the receiving tube. It was found necessary to keep a cork collar in the mouth of the receiving tube in all cases, so as to minimise the loss of heat caused by the hot body coming into contact with that part of the iron tube which is outside the body of the calorimeter.

The method of experimenting was as follows:

(1) The position of the end of the mercury thread in the reading tube was noted every 5 minutes.

(2) When sufficient readings had been taken to render it possible to deduce the law of variation due to outside influences the hot body was introduced.

(3) The reading tube was again observed as soon as possible and readings were taken, usually at intervals of 1 or 2 minutes, until the law of variation due to external causes could be estimated.

Thus by combining the results of (1) and (3) the necessary correction could be applied, as in the following example:

Time.	Scale reading.	Mean difference for 1 minute.	
0′	84·0		
5′	88·0	0·8	
10′	92·0		
15′	96·0		
16′	458·0		Hot body introduced.
17′	294·7		
19′	297·0		
20′	299		
22′	301·0	0·88	
24′	302·0		
27′	304·0		

Thus the average correction is 0·84 mm. per minute.

Between 10′ and 20′ mercury moves 299 − 92 mm. = 207; deduct 0·84 × 10 for external heating, and this leaves 207 − 8·4 = 198·6 mm. as effect due to hot body.

Thus if the weight, and the original and final temperatures of the hot body are known, its specific heat can be calculated when the heat value of the scale divisions is known, and this was obtained by using a known weight of mercury heated to about 100° C.

In the above table it will be seen that when the hot body was introduced the mercury rushed forward 362 mm. in the tube, and then almost immediately withdrew 163·3 mm.; this outrush and subsequent contraction is due to the sudden heating and expansion of the receiving tube, which speedily parts with its heat to the surrounding mercury, hence the contraction.

Some trouble was experienced in graduating the instrument owing to the difficulty of conveying the mercury from the hypsometer in which it was heated to the calorimeter; this was at last managed by enclosing the mercury in three test tubes, this giving three thicknesses of glass, and two air spaces for the heat to pass through. The inner test tubes were kept steady by means of cork collars at their ends, and the three were fastened together and fixed in a cork, to which was attached

a handle of copper wire. By means of this arrangement the temperature of the mercury remained constant near the boiling point when withdrawn from the hypsometer for 15″, and then began to fall, when cooling effect had penetrated, at the rate of 0·2° C. per 15″. The entire series of operations of removing the cork from the receiving tube, reading the temperature of the hot mercury, removing the thermometer, carrying the mercury to the receiving tube and pouring it in, and replacing the cork, was always completed in less than 1 minute, so that the reading tube could be observed; thus the hot mercury was not exposed much, if any, beyond the 15″ during which its temperature had been proved to remain steady.

It will be seen later that these precautions were probably not sufficient to guarantee the mercury arriving in the calorimeter at the temperature of the steam. It is not unlikely that it was cooled considerably in passing over the cooler part of the test tube.

TABLE OF EXPERIMENTS.

Exp.	Substance used.	Weight.	Initial temperature.	Final temperature.	No. of divisions of calorimeter scale moved over.	Correction for external temperature variation.	Scale divisions corresponding to one heat unit.
A	Mercury...	50·28 g.	99°·8 C.	13°·4 C.	195·0	61·6	0·922
B	,,	53·45 ,,	99°·6 ,,	14°·0 ,,	203·5	42·0	1·060
C	Platinum	3·502 ,,	99°·6 ,,	14°·4 ,,	59·0	46·0	1·35
D	Mercury...	60·59 ,,	98°·8 ,,	14°·4 ,,	222	35	1·098
E	,,	100·37 ,,	65°·0 ,,	14°·9 ,,	215	16·8	1·187
F	Platinum	23·24 ,,	98°·2 ,,	14°·4 ,,	170	84	1·363
G	,,	23·24 ,,	99°·2 ,,	14°·9 ,,	152·5	68·4	1·325

The specific heat of Platinum was taken as 0·0324, that of Mercury 0·0333.

In the above experiments it will be noticed that the results obtained from mercury increased at each fresh attempt, and this was due to successive improvements in the method of preventing loss of heat. In experiment A, owing to want of practice, several seconds were wasted in pouring the hot mercury into the receiving tube; in B, this was done much more expeditiously; for D, the cork collar was introduced into the mouth of the receiving tube, thus preventing loss of heat by contact with the cold iron; while in E, a larger quantity of mercury was heated to 65° C. instead of to nearly 100° C., the cork collar being retained, thus the loss of heat was still further reduced.

In all these experiments however the mercury had to flow over the cooler parts of the inner test tube, of which about two inches towards the mouth were not exposed to the steam of the hypsometer, being surrounded by cork and the string used in fixing the three tubes firmly together; and thus owing to the large extent of the surfaces in contact, the glass must have cooled the mercury appreciably. The platinum experiments agree fairly well together, and it is easy to see that the loss of heat must be less than for the mercury, for the solid platinum would shoot more rapidly out of the test tube into the receiving tube, and further, the surface in contact with the cooler parts of the test tube while passing out would be much less than in the case of a liquid like mercury; evidently also the cork collar would be less necessary for the platinum; it was used in F and G but not in C, which gives a result very nearly the mean between F and G.

Attempts were also made to estimate the temperature of copper and platinum heated in the Bunsen flame by means of this calorimeter. To do this a piece of platinum or copper wire was coiled up and placed on a support about 12 inches above the mouth of the receiving tube; through this coil a piece of fine platinum wire was passed leading vertically down to the receiving tube, in which its lower end was kept by means of a platinum weight. A screen was placed below the little coil, and the Bunsen flame was allowed to play on it until it was at a steady white heat; the screen was then removed, the cork

withdrawn from the receiving tube, and the coil was pushed off its support, and being guided by the fine wire it fell right into the receiving tube, and the cork was replaced. In the first and third of the following experiments some time was lost in replacing the cork, and thus they both give a lower result than the second, and as this cause of error was about the same in both these cases they agree fairly together.

1ST EXPERIMENT.—Platinum used. Weight of platinum 3·502 grammes. Final temperature of calorimeter 15°·2 C. 1·345 scale divisions correspond to 1 heat unit.

This number is the mean of the three previous experiments on platinum.

0·0373 = specific heat of platinum from 0° to 1000° C.

Observations on Calorimeter.

Time.	Reading tube.		
0	12	Gain per 1′ 2·6	Mean gain 2·43.
5	25		
10	166		
12	178		
16	193		
20	203·7	Gain per 1′ 2·26	
21	207·0		
25	215·0		

Reading at 20′	203·7
0	12
	191·7
External heating	48·6
Heat due to platinum	143·1

$$\text{Heat units given out} = \frac{143{\cdot}1}{1{\cdot}345}.$$

Then $(T - 15°{\cdot}2)$ = fall in temperature of Platinum

$$= \frac{143{\cdot}1}{1{\cdot}345} \times \frac{1}{3{\cdot}502 \times 0{\cdot}0373} = 814{\cdot}5,$$

T = temperature of platinum = 829°·7 C.

2ND EXPERIMENT.—Platinum used. Final temperature of calorimeter 15°·5 C. Other numbers as before.

Observations on Calorimeter.

Time.	Reading tube.		
0	25·0	Mean gain per 1′ 1·55	Mean gain 1·37.
5	32·0		
10	40·5		
13	111·0		
15	175·0		
20	213·0		
25	225·0		
30	234·5	Mean gain per 1′ 1·19	
35	239·5		
38	244·0		

Reading at 30′	234·5
0	25·0
	209·5
External heating	41·1
	168·4

$$\text{Heat units given out} = \frac{168{\cdot}4}{1{\cdot}345},$$

$$(T - 15°{\cdot}5') = \frac{168{\cdot}4}{1{\cdot}345} \times \frac{1}{3{\cdot}502 \times 0{\cdot}0373} = 958{\cdot}5,$$

temperature of platinum = 974° C.

3RD EXPERIMENT.—Copper used. Final temperature of calorimeter, 15°·7 C. Weight of copper, 1·186 grammes. Specific heat taken as 0·100,

Observations on Calorimeter.

Time.	Reading tube.		
0	60·5	Mean gain per 1′ 0·75	Mean gain 0·87.
6	64·9		
10	68·0		
12	146·0		
15	198·0		
18	205·0	Mean gain per 1′ 1·0	
20	207·0		
23	210·0		

Reading at 20	207·0
0	60·5
	146·5
External heating	17·4
Heat of copper	129·1

$$\text{Heat units given out} = \frac{129{\cdot}1}{1{\cdot}345}.$$

$$(T - 15°{\cdot}7) = \frac{129{\cdot}1}{1{\cdot}345} \times \frac{1}{1{\cdot}186 \times 0{\cdot}1} = 809{\cdot}3.$$

Temperature of copper = 825° C.

G. BROWN.

No. 15. CLÉMENT AND DÉSORMES' EXPERIMENT ON THE SPECIFIC HEATS OF GASES.

A LARGE number of observations have from time to time been taken with a simple arrangement of Clément and Désormes' experiment. A large globe about twelve inches in diameter has its neck connected with a wide three-way tube, one opening leading to a sulphuric acid pressure-gauge, and the other connected by wide india-rubber tubing with a piece of wide glass tubing. For the compression experiments the glass tubing dips under mercury, and the sudden communication between inside and outside is established by simply lifting up the tube; while for the rarefaction experiments the india-rubber tube is closed by an iron bar buttoned down, and the communication can be made by releasing the button and lifting up the bar.

To minimise the loss of heat by radiation a small quantity of strong sulphuric acid is introduced into the globe, and the air which entered had always to pass through a large flask filled with very coarse lumps of fused calcium chloride.

The experiments shew that it only requires a little practice to be able to get any desired result with the apparatus, for if the communication is established for too short a time the result gives too great a ratio, while if the time be too long the result is too small. It seems not to be possible to re-arrange the apparatus in any simple way to ensure automatically that the opening shall be sufficiently long for the pressure to be equalised and no longer, and this point becomes therefore to some extent a matter of conscience with the observer. The results obtained point to 1·33 as the value of the ratio of the specific heats to be obtained from this apparatus.

The following table by Messrs Carnegie and Read gives a specimen of the observations.

Pressure gauge readings in centimetres.				γ
Before opening.		After opening.		
Left.	Right.	Left.	Right.	
A. Compression.				
11·48	27·64	17·4	21·68	1·33
15·1	24·00	18·28	20·8	1·34
14·27	24·83	18·08	21·00	1·33
B. Rarefaction.				
23·55	15·47	20·38	18·68	1·32
21·85	17·22	19·98	19·09	1·34

W. N. SHAW.

No. 20. EXPERIMENTS TO DETERMINE THE TENSION OF AQUEOUS VAPOUR IN PRESENCE OF A MIXTURE OF WATER AND SULPHURIC ACID OF KNOWN COMPOSITION, AT KNOWN TEMPERATURE.

It was first necessary to make the mixture of known proportions of water and sulphuric acid.

The method adopted was to determine the S. G. of the mixture, and hence get its per-centage composition from the tables.

First a bottle of commercial "pure redistilled" acid was taken. This could not be tested by the S. G. method, since for mixtures from 95° to 100 per cent. acid there is no variation of density, and very little above 90 per cent.

A portion of the commercial acid was poured into a flask holding about ½ a litre. The flask and acid weighed 1124·373 grammes (all weights given in grammes).

The acid was then poured off into a stoppered bottle destined to hold the mixture, and the emptied (but not dried) flask weighed 122·062 grams. This gives for the weight of the commercial *acid* 1002·311.

The flask was then washed, and the same operation repeated with water, the water being poured into the same stoppered bottle.

As the water had to be poured in by very small quantities at a time (owing to the heat developed), there was a certain loss from drops that ran down the outside of the flask after each pouring. An idea of the amount of water thus lost was got by standing the flask on a glass plate, which was weighed with it before and after, but this would not account for the whole loss, owing to evaporation.

Weight of flask and water	665·178
„ „ emptied	120·368
Correction for spilling	·310
This gives for the weight of the *water*	544·500

(In all dealings with the acid, care was taken to exclude the air as much as possible.)

There was then in the bottle a mixture, which we call Mixture I. as follows:

Commercial acid	1002·311
Water	544·500
	1546·811

The method adopted for determining the specific gravity was by means of a glass bob, loaded with mercury, and hung by a platinum wire to the scale of a balance. A rather thick wire was used to avoid the danger of breakage. No error is introduced on account of the weight of the wire, if care is taken to have it always immersed to the same depth. This was got by using the same beaker for all the weighings, a mark on it shewing the proper level of the liquid.

What we want to obtain is the specific gravity of the various mixtures of water and acid, *i.e.* the ratio of the weight of a volume of the mixture at 15° to that of the same volume of water at 4°.

Let weight of bob in air $= W$,
„ „ water at $t_1° = W'$,
„ „ mixture at $t_2° = W''$,
specific gravity of water at $t_1° = d_1$
(compared with *water at* 4°),
„ mixture at $t_2° = \delta_2$
(compared with *mixture at* 15°).

(The specific gravity of all these mixtures is taken at 15°, compared to water at 4°, in Kohlrausch.)

Then specific gravity of mixture

$$= \frac{W - W''}{W - W'} \cdot \frac{d_1}{\delta_2}.$$

Now $\frac{1}{\delta_2} = 1 + k\,(t_2 - 15)$ where k = coefficient of expansion of the mixture.

According to Kohlrausch $k = \cdot00016 + \cdot00001 \times p$ where p is the percentage of pure acid in the mixture.

Hence specific gravity of mixture

$$= \frac{W - W''}{W - W'} . d_1 . \{1 + (\cdot00016 + \cdot00001 \times p)\,(t_2 - 15)\}.$$

For this formula, p need only be known approximately.

The following weighings were taken :

weight of bob in air (W) 26·0356,
" " water (W') 16·6367, temp. 11·6,
" " Mixture I. (W'') 11·6835, temp. 13·5.

Hence $W - W' = 9\cdot3989$

$W - W'' = 14\cdot3521,$

$t_1 = 11\cdot6\,; \quad \therefore \quad d_1 = \cdot99959,$

$t_2 = 13\cdot5\,; \quad \therefore \quad t_2 - 15 = -1\cdot5,$

$\log d_1 = \bar{1}\cdot9998219$

$\log (W - W') = \cdot9730770$

$\log \frac{d_1}{W - W'} = \bar{1}\cdot0267449.$

Now approximately $p = \frac{1002\cdot3}{1546\cdot8} \times 100 = 64\cdot8$. (This is assuming the commercial acid to be pure.)

Hence $\frac{1}{\delta_2} = 1 - (\cdot00016 + \cdot000648) \times 1\cdot5$

$= \cdot998788,$

$\log (W - W'') = 1\cdot1569154$

$\log \frac{1}{\delta^2} = \bar{1}\cdot9994732,$

$\log \frac{d_1}{W - W'} = \bar{1}\cdot0267449,$

log specif. grav. = ·1831335 ;

therefore specific gravity of (I.) = 1·5245.

This corresponds to a strength of 62 per cent.

Hence the 1546·811 grammes contain 959·023 of pure acid.

Hence the 1002·311 grammes of commercial acid contain this quantity of pure acid.

This gives for the percentage composition of the commercial acid 95·68 per cent., H_2SO_4.

In order to take the weighing, a portion of mixture (I.) had to be poured out into a beaker.

There was not enough of the mixture for this portion to be wasted, so the following method was adopted:

The empty beaker was weighed (α).

Then the beaker with the portion poured out (β).

Then, after the specific gravity weighing (which involved inserting the bob and the thermometer) the weight was taken again (γ).

Then the mixture was poured back into the bottle, and the emptied beaker weighed (δ);

$(\beta - \alpha)$ is the weight poured out,

$(\gamma - \delta)$ is the weight poured back;

$\therefore$ $(\beta - \alpha - \gamma + \delta)$ is the weight lost in the observation,

$\alpha =$	94·774	$\beta =$	595·090
$\gamma =$	594·745	$\delta =$	95·731
	689·519		690·821
			689·519
Loss $= (\beta + \delta - \alpha - \gamma) =$			1·302

This quantity gives $\left\{\begin{matrix}\text{Commercial acid} & \cdot 840 \\ \text{Water} & \cdot 462\end{matrix}\right\} = 1{\cdot}302.$

Mixture I. in the bottle then consists of:

Comm. acid	1001·471
Water	544·038
	1545·509

There is now added to the above more water, weighed in the same manner as previously described.

Weight of water added 275·739.

This forms Mixture II., whose composition is

Comm. acid	1001·471
Water	819·777
	1821·248

Mixture II. was then treated as Mixture I. had been before.

Weight of bob in Mixture II. (W'') = 12·6320 temp. = 14°7.

Hence $W - W'' = 13{\cdot}4036$, $t_2 - 15 = -0{\cdot}3$.

p is now the percentage of Mixture II., which is

$$95{\cdot}68 \times \frac{1001{\cdot}471}{1821{\cdot}248} = 52{\cdot}6.$$

Hence $$\frac{1}{\delta_2} = 1 - (\cdot 00016 + \cdot 000526) \times \cdot 3$$

$$= \cdot 999794,$$

$$\log (W - W'') = 1{\cdot}1272216$$

$$\log \frac{1}{\delta_2} = \bar{1}{\cdot}9999105$$

$$\log \frac{d_1}{W - W'} = \bar{1}{\cdot}0267449$$

log specific gravity = ·1538770

therefore specific gravity of (II.) = 1·4252.

This corresponds to a strength of 52·6 per cent.

Hence the 1821·248 grams contain 957·976 of pure acid.

Hence the 1001·471 grams of commercial acid contain this quantity of pure acid.

This gives for the percentage of the comm. acid 95·66 per cent.

In pouring out and back the mixture for taking the specific gravity weighings were taken as described for Mixture I. These were:

$\alpha =$ 94·774	$\beta =$ 551·015
$\gamma =$ 550·695	$\delta =$ 95·585
645·469	646·600
	645·469
	Loss $= \beta + \delta - \alpha - \gamma =$ 1·131

This gives $\left\{\begin{matrix}\text{Commercial acid} & \cdot 622 \\ \text{Water} & \cdot 509\end{matrix}\right\} = 1 \cdot 131.$

Mixture II. in the bottle then consists of

Comm. acid	1000·849
Water	819·268
	1820·117

There is now added to the bottle more water.

The weight, determined as before, being 299·627.

This forms Mixture III., whose composition is

Comm. acid	1000·849
Water	1118·895
	2119·744

The same process is now repeated with Mixture III.:

$$W'' = 13 \cdot 3029, \quad t_2 = 14 \cdot 7.$$

Hence $W - W'' = 12 \cdot 7327, \quad t_2 - 15 = -0 \cdot 3,$

$$p = \text{percentage of III.} = 95 \cdot 67 + \frac{1000 \cdot 85}{2119 \cdot 75} = 45 \cdot 2;$$

$$\therefore \frac{1}{\delta_2} = 1 - (\cdot 00016 + \cdot 000452) \times \cdot 3 = \cdot 9998164,$$

$$\log (W - W'') = 1 \cdot 1049260$$

$$\log \frac{1}{\delta_2} = \cdot 9999203$$

$$\log \frac{d_1}{W - W'} = \bar{1} \cdot 0267449$$

$$\log \text{specific gravity} = 1 \cdot 1315912$$

$\therefore$ specific gravity $= 1 \cdot 3539$ (of Mixture III.).

This corresponds to a strength of 45·21 per cent.

Working as before, this gives as the percentage of the comm. acid 95·75 per cent.

The percentage compositions of the commercial acid thus derived from three separate experiments, are:

$$\left.\begin{matrix}95 \cdot 68 \\ 95 \cdot 66 \\ 95 \cdot 75\end{matrix}\right\} \text{mean} = 95 \cdot 70.$$

Taking this mean value of 95·70 for the percentage of the commercial acid, the percentage of Mixture III. is found to be 45·185.

From these values may be calculated the following table for the formation of mixtures of any required strength:—1 part of Mixture III. to

Formula.	Commercial Acid.	Water.	Percentage of H_2SO_4 in the mixture.
$SO_3 + 2H_2O$	3·5033	„	84·483
„ 3 „	1·2386	„	73·134
„ 4 „	·6177	„	64·474
„ 5 „	·3282	„	57·647
„ 6 „	·1593	„	52·128
„ 8 „	„	·0328	43·750
„ 10 „	„	·1988	37·692
„ 12 „	„	·3648	33·108
„ 18 „	„	·8628	24·257

[The method employed to measure the pressure of water vapour was that known as the chemical method. Ordinary air was first 'saturated' with the vapour arising from the known acid mixture by drawing it by means of an aspirator *A* first through a large bottle *F* and secondly through a wide U-tube *E* each containing fragments of ignited pumice moistened with the acid mixture. The delivery tube of the air passed to the bottom of the bottle *F* and the exhaust tube opened in the neck. The U-tube *E* was put on in addition by way of making allowance for the alteration in composition of the acid in consequence of the passage of the air. The temperature of the 'saturated' air was taken by means of a thermometer *T* in the second limb of the U-tube. The air thus saturated was drawn by means of the aspirator *A* through weighed drying tubes *C*, *D* filled with pumice and concentrated sulphuric acid and thence through a chloride of calcium valve *B* to the aspirator. The aspirator and drying tubes are described in detail in the *Cambridge Philosophical Transactions* 1882[1]. The aspirator is

[1] Shaw, "On the Measurement of Temperature by Water Vapour Pressure."

provided with a tap g at the bottom to stop the flow of water when necessary, a gauge tube to watch the rate of flow, a thermometer T' and an exhaust tube to facilitate refilling. The drying tubes have thick tubular glass stoppers bent over so as to enable the connections between them and the rest of the apparatus to be made by mercury joints. There was a pinch-cock k between the calcium chloride valve B and the aspirator and the exhaust tube in the aspirator was likewise closed by an india-rubber tube and pinch-cock h.]

PRECAUTIONS TO BE OBSERVED.

The air tube in the aspirator should go down to the bottom, in order that the flow may be constant.

The apparatus should be tested for leaks, thus: after filling the aspirator close cocks h and k firmly, and open g. A little water will run out, but the running should entirely cease, otherwise there is a leak. Then close g and open h, to equalise the pressure again. Then, when ready to begin, close h very firmly, open k, and then g.

There should be a clear air-passage at C, D, E, and F, especially at the end of the experiment.

E and F should be occasionally turned on one side, so as to re-moisten the pumice.

The thermometer in E should be read frequently, and at regular intervals. It is never constant.

If the air-tube into F be stopped, and g opened, the mercury will be sucked over into the tubes, but E and F and the connecting tubes may be tested for leaks by removing C and D and substituting a tightly fitting rubber tube. In this way a leak may be discovered anywhere but in the mercury joints themselves, and a leak there is not possible if they are properly adjusted.

The volumes were measured in a marked litre flask.

Observations.

Solution $SO_3 + 8H_2O$.

Weight of tubes $\begin{cases} 171{\cdot}6855, & 184{\cdot}6020 \\ 171{\cdot}7793, & 184{\cdot}6050. \end{cases}$

(W) Increase of weight = ·0938 + ·0030 = ·0968.

(V) Volume of water run out = ·016 cub. metre.

Final temperature of aspirator (t') = 14·4,

$\therefore e_{t'} = 12{\cdot}220$, and $1 + \alpha t' = 1{\cdot}0497$.

Barometer (H) = 754·2,

Temperature $t = \underline{13{\cdot}724}$ { mean of 16 observations.

The formula is

$$\frac{e}{H-e} = \frac{760}{H-e_{t'}} \cdot (1+\alpha t') \cdot \frac{W}{{\cdot}622 \times 1293 \times V}.$$

Hence $$\frac{e}{754{\cdot}2-e} = {\cdot}0008088.$$

$$\therefore e = \underline{6{\cdot}0512}.$$

Regnault's number for e at this temperature is 5·707.

Solution $\underline{SO_3 + 5H_2O}$.

Weight of tubes { 171·766, 184·583, 171·801, 184·590.

Increase of weight (W) = ·035 + ·007 = ·042.

Volume (V) = ·016 cubic metre.

Final temperature of aspirator (t') = 13·5,

$\therefore e_{t'} = 11{\cdot}530$, and $1 + \alpha t' = 1{\cdot}0494$.

Barometer (H) = 758·8.

Temperature $t = \underline{13{\cdot}332}$ { mean of 16 observations.

Hence $$\frac{e}{758{\cdot}8-e} = {\cdot}0034914,$$

$$\therefore e = \underline{2{\cdot}6340}.$$

Regnault's number for e at this temperature is 2·387.

F. M. YOUNG.

[The differences may possibly be due to the method of saturation adopted.]

No. 21. VERIFICATION OF REGNAULT'S FORMULA FOR THE WET AND DRY BULB THERMOMETERS.

THE apparatus arranged for this purpose is shewn in the figure (fig. 9). *A*, *B*, and *C* are three glass globes each pro-

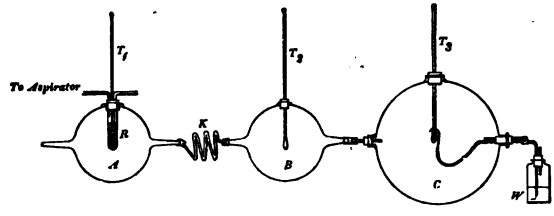


Fig. 9.

vided with three necks; the globes are mounted on stands so that the middle neck of each opens vertically. In the first is placed a Regnault hygrometer *R*, with its thermometer T_1. The current of air for cooling the ether is provided by a water-aspirator of the Magnus pattern, which has proved itself to be very convenient for the purpose. The silver thimble of the hygrometer is near the centre of the globe, and the observer can view it as closely as he pleases without danger of interfering with the deposit. It is generally found that the deposit is most easily visible if the direction of the light which illuminates the thimble be inclined to the line between the thimble and the observer at an angle rather less than a right angle.

Between *A* and *B* is a coil of copper-tubing *K*. This is intended to bring the air which has been cooled by passing over the cold surface of the thimble back to the temperature of the air.

In *B* is a dry bulb thermometer T_2, intended to determine the temperature of the air. In *C* is a wet bulb thermometer T_3.

The bulb is covered with muslin and kept moist by means of a wick which passes through glass tubes to the water bottle *W*.

Air is made to pass through the whole set of bulbs by the use of foot bellows; it may be sent through in its natural state, or by interposing a calcium-chloride bottle or a bottle of pumice moistened with water it may be delivered either dried or moist.

The formula for the reduction of the wet and dry bulb observations is taken from Jelinek's *Anleitung zur Anstellung Meteorologischer Beobachtungen*, and is Regnault's formula altered in shape. It is the basis of Jelinek's Psychrometer tables for temperatures of the wet bulb above the freezing point. The formula is

$$e'' = e' - \cdot 0009739t'(t-t') - \cdot 5941(t-t') - \cdot 0008(t-t')(b-755).$$

It turned out as was to be expected, that the temperature of the wet bulb depends upon the rate at which the air is driven through the apparatus, the variation being something like a degree for ordinary atmospheric states.

The results obtained give the observations of the lowest temperature of the wet bulb.

	Dry Bulb.	Wet Bulb.	Tension of Vapour.	Calculated Dew Point.	Dew Point observed between	Observer.
Air of Room	11·4	7·85	5·858	3°·4	2°·5...2°·6	G. B.
	10·4	7·1	5·553	2°·6	2°·3...2°·7	J. T. K.
	10·8	7·2	5·417	2°·3	2°·2...2°·4	,,
	10·9	7·2	5·379	2°·2	2°·3	,,
Dry Air	11·7	7·15	4·861	0°·6	−1·23...−1·13	G. B.
	10·4	5·6	3·920	−2°·1	−2 ...−2·15	J. T. K.
	10·5	5·7	3·941	−2°·0	−2°·05	,,
	10·6	5·8	3·963	−1°·9	−2°·15...−2°·2	,,
Moist Air	11·8	11·1	9·455	10°·4	10°·8...11°·1	G. B.
	10·7	9·4	8·017	8°·0	7°·75...8°·2	J. T. K.

W. N. SHAW.

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